

PHILOSOPHICAL
TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCXL.

PART II.

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PHILOSOPHICAL

TRANSACTIONS

ROYAL SOCIETY

LONDON

FOR THE YEAR 1841

PART II

LONDON

ADJUDICATION of the MEDALS of the ROYAL SOCIETY for the year 1840 by
the PRESIDENT and COUNCIL.

THE COPLEY MEDAL to Professor LIEBIG, Foreign Mem. R.S., &c., for his discoveries in Organic Chemistry, and particularly for his development of the composition and theory of Organic Radicals.

ANOTHER COPLEY MEDAL to M. STURM, Foreign Mem. R.S., &c., for his "Mémoire sur la Résolution des Equations Numériques," published in the Mémoires des Savans Etrangers for 1835.

THE RUMFORD MEDAL to M. BIOT, Foreign Mem. R.S., &c., for his researches in, and connected with, the circular Polarization of Light.

THE ROYAL MEDAL in the department of Physics, to Sir JOHN F. W. HERSCHEL, Bart., K.H., V.P.R.S., &c., for his Paper entitled, "On the Chemical Action of the Rays of the Solar Spectrum on Preparations of Silver and other Substances, both metallic and non-metallic, and on some Photographic Processes," published in the Philosophical Transactions for 1840.

THE OTHER ROYAL MEDAL, not having been awarded in the department of Geology, was awarded in that of Physiology, to CHARLES WHEATSTONE, Esq., F.R.S., &c., for his Paper entitled "Contributions to the Physiology of Vision," published in the Philosophical Transactions for 1838.

ANNOUNCEMENT OF THE RESULTS OF THE 1954 ELECTIONS
TO THE HOUSE OF REPRESENTATIVES

The results of the 1954 elections to the House of Representatives are as follows: The Republican Party has won 223 seats, the Democratic Party 193 seats, and the Independent Party 1 seat.

The following table shows the results of the elections in each of the 48 States and the District of Columbia:

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CONTENTS.

- XII. THE BAKERIAN LECTURE.—*On the Theoretical Explanation of an apparent new Polarity in Light.* By G. B. AIRY, Esq., M.A., F.R.S., Astronomer Royal. page 225
- XIII. *On the Nervous System.* By Sir CHARLES BELL, F.R.S., &c. 245
- XIV. *Researches on the Tides.—Twelfth Series. On the Laws of the Rise and Fall of the Sea's Surface during each Tide.* By the Rev. W. WHEWELL, B.D., F.R.S., Fellow of Trinity College, Cambridge. 255
- XV. *Contributions to the Chemical History of Archil and of Litmus.* By ROBERT KANE, M.D., M.R.I.A. Communicated by FRANCIS BAILY, Esq., V.P.R.S., &c. &c. 273
- XVI. *On the influence of Iodine in rendering several Argentine Compounds, spread on Paper, sensitive to Light, and on a new Method of producing, with greater distinctness, the Photographic Image.* By Mr. ROBERT HUNT. Communicated by Sir J. F. W. HERSCHEL, Bart., K.H., V.P.R.S., &c. &c. &c. 325
- XVII. *Description of an Escapement for an Astronomical Clock, invented by the late Captain HENRY KATER, F.R.S., &c., drawn up from his own Memorandums by his Son EDWARD KATER, Esq.* Communicated by Sir J. F. W. HERSCHEL, Bart., K.H., V.P.R.S., &c. &c. &c. 335
- XVIII. *On the Constitution of the Resins. Part IV.* By JAMES F. W. JOHNSTON, Esq., M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham. 341
- XIX. *On the Constitution of the Resins. Part V.* By JAMES F. W. JOHNSTON, Esq., M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham. 361
- XX. *Experimental Researches on the Strength of Pillars of Cast Iron, and other Materials.* By EATON HODGKINSON, Esq. Communicated by PETER BARLOW, Esq., F.R.S., &c. 385

XXI. <i>On the Minute Structure and Movements of Voluntary Muscle.</i> By WILLIAM BOWMAN, Esq., Demonstrator of Anatomy in King's College, London, and Assistant Surgeon to the King's College Hospital. In a Letter addressed to ROBERT BENTLEY TODD, M.D., F.R.S., Professor of General Anatomy and Physiology in King's College, London. Communicated by Professor TODD	457
XXII. <i>An Account of Experiments on the Reflecting Telescope.</i> By the Right Honourable Lord OXMAN TOWN, F.R.S., &c.	503
XXIII. <i>Researches in Embryology. Third Series: A Contribution to the Physiology of Cells.</i> By MARTIN BARRY, M.D., F.R.S., F.R.S.E., Fellow of the Royal College of Physicians in Edinburgh.	529
XXIV. <i>On the Corpuscles of the Blood.</i> By MARTIN BARRY, M.D., F.R.S., F.R.S.E., &c.	595
<i>Index</i>	613

APPENDIX.

<i>Presents</i>	[1]
<i>Meteorological Journal kept at the Apartments of the Royal Society, by order of the President and Council.</i>	

PHILOSOPHICAL TRANSACTIONS.

XII. THE BAKERIAN LECTURE.—*On the Theoretical Explanation of an apparent new Polarity in Light.* By G. B. AIRY, Esq. M.A. F.R.S., Astronomer Royal.

Received June 14,—Read June 18, 1840.

IN the Report of the Seventh Meeting of the British Association*, and in that of the Eighth Meeting†, Sir DAVID BREWSTER has given a short account of experiments which have led him to infer the existence of a *polarity*, in the rays of homogeneous light, having regard only to the sequence of colours in the spectrum. I am aware that Sir DAVID BREWSTER has announced his intention of publishing a more elaborate paper upon these experiments. But as the leading facts of the experiments have now been communicated to the public nearly two years, and by Sir DAVID BREWSTER himself, and as the accounts have been sufficiently explanatory to enable any other person to repeat the experiments, and as various persons have in consequence repeated them, there cannot, I conceive, be the most trifling impropriety in making the whole subject a matter of discussion, experimental and theoretical.

As the experimental facts observed by myself differ from those of Sir DAVID BREWSTER in a degree which, as regards the experiment, is trifling (and might easily pass unobserved), but which, as regards the theory, is important; I think it necessary to give the following brief history. My first repetition of the experiment was made in October, 1839, in consequence of a friend requesting my opinion upon a proposed theoretical explanation. To that friend I immediately communicated (by letter) the experimental results at which I had arrived, with a request that he would verify them; and he did accordingly verify them, as far as the apparatus in his hands allowed. These results suggested to my mind the general train of the theoretical explanation; and the numerical calculations necessary for following it into details were immediately placed in the hands of a computer. The incessant occupations incidental to my office prevented me from even looking at the calculated numbers till the month of May, 1840, when the remarks of another friend recalled my attention to the subject.

* Transactions of the Sections, p. 12. † Transactions of the Sections, p. 13.

I mention these matters merely for the purpose of showing distinctly that the observation of the facts was with me long anterior to the explanation, and that therefore no leaning in favour of the theory can have warped my judgment in the perception of experimental facts not wholly coinciding with Sir DAVID BREWSTER'S. Indeed, I should never have thought of opposing my evidence on a matter of observation to that of the Father of Modern Experimental Optics, unless the reasons for disagreement were not only, in my judgment, well-grounded, but also unmingled and independent.

The facts, then, as I have observed them, are as follows:

1. When a prismatic spectrum is viewed, *out of focus*, bands are formed by placing a piece of mica of a proper thickness (indefinite within wide limits) to cover that half of the pupil of the eye, which is on the same side as the violet end of the spectrum.

2. No bands are formed with any thickness of mica if it is placed on the same side as the red end of the spectrum.

3. When the eye is too far off to see the spectrum distinctly; then, upon passing the mica before the eye from the violet end of the spectrum, bands are seen advancing in the same direction over the spectrum.

4. When the eye is too near to the spectrum to see it distinctly; then, upon passing the mica from the violet end of the spectrum, bands are seen advancing in the opposite direction over the spectrum.

5. If the eye be so far off, and the spectrum in consequence seen so indistinctly, that the ruddy portions are nearly mingled with the blue; upon applying the mica to cover half the pupil on the side corresponding to the violet end of the spectrum, bands are seen very well defined, but narrow.

6. If the eye and mica approach to the position of distinct vision of the spectrum, the bands become somewhat broader, and near the position of distinct vision sometimes disappear. On still approaching to the spectrum, the bands reappear and become narrower, but are not, I think, seen so distinctly as when the eye is too far off for distinct vision. I know not, however, whether this may depend upon the practical difficulty of that part of the experiment.

7. Bands which are visible when the mica is on the violet side and invisible when it is on the red side, never occur when the spectrum is pure.

8. Bands are frequently visible when the spectrum is pure; but in that case they can be seen equally well, whether the mica be advanced from the violet side or from the red side.

The bands mentioned in No. 8. have been long since observed and explained by Mr. TALBOT*, and of these therefore I shall make no further mention.

The general outline of the explanation of the bands seen when the spectrum is out of focus, is as follows:

* London and Edinburgh Philosophical Magazine, vol. x. p. 364.

1. By retarding the light which falls upon a portion of the pupil of the eye, bands are formed in the indistinct image produced by any one kind of homogeneous light.

2. These bands are not symmetrical with regard to the centre of the indistinct image; and the extent of asymmetry depends on the retardation.

3. Therefore if light issues from a number of luminous points of such character that the value of retardation changes gradually from one to another, the position of the bands, as measured from the centre of the indistinct image of each luminous point, will gradually change from one to another.

4. If then these luminous points be spectrally separated in one certain direction, the centres of the indistinct images will be separated in a corresponding manner, and the bands produced by all these luminous points may be made to coincide, and thereby to produce strong bands, in the confused spectrum formed by the aggregate of all the indistinct images.

5. But if the luminous points be spectrally separated in the opposite direction, the bands will be removed further from coincidence than before, and all trace of them will be lost in the confused spectrum formed by the aggregate.

6. Whether the retina be too near to the pupil, or too far from it, for distinct vision of the luminous points, the spectral separation must be such as to carry the points from which issues the most retardable light towards the side on which the retarding plate is placed.

The remainder of this paper contains the mathematical development of this explanation.

Let the wave of light, issuing from any luminous point, have, after passing the lens of the eye, the form of a spherical surface converging to the centre of the sphere. Let the radius of the spherical surface be c , and let the distance of the retina from the lens be $c + a$ (this assumption corresponds to the supposition that the luminous point is too far off for distinct vision), and let it be required to investigate the intensity of light on a point of the retina, whose distance, from the point defined by drawing a line from the luminous origin through the centre of the sphere, is b . Let x be measured from the centre of the spherical surface along that line; and let y be measured in the direction parallel to b , x and y being used to define a point on the wave surface. Then $x^2 + y^2 = c^2$. There is no necessity for introducing another co-ordinate of the wave-surface, as its effect would only be, to introduce a constant multiplier in the result.

The distance from the point x, y , to the point on the retina is

$$\sqrt{(x+a)^2 + y^2 - b^2} = \sqrt{c^2 + 2ax - 2by + a^2 + b^2}.$$

If for x we put its value $c - \frac{y^2}{2c}$ (as far as the second power of y), this expression

becomes $\sqrt{\left\{c + a^2 + b^2 - 2by - \frac{a}{c}y^2\right\}}$; and, expanding to the second power of

y , and putting e^2 for $c + a^2 + b^2$, it is

$$e - \frac{b}{e}y - \left(\frac{b^2}{2e^3} + \frac{a}{2ce}\right)y^2.$$

With the small values of b , of which we shall have occasion to treat, b^2 will be much less than $\frac{ae^2}{c}$. Neglecting therefore the first multiplier of y^2 , and putting ξ for the distance from the point x, y to the point on the retina,

$$\begin{aligned}\xi &= e - \frac{b}{e}y - \frac{a}{2ce}y^2 \\ &= e + \frac{cb^2}{2ea} - \frac{a}{2ce}\left(y + \frac{cb}{a}\right)^2 \\ &= f - \frac{a}{2ce}\left(y + \frac{cb}{a}\right)^2,\end{aligned}$$

where $f = e + \frac{cb^2}{2ea}$.

If now we suppose (as in diffractions generally) that every part of the great wave, after leaving the lens, is simultaneously the origin of a small wave diverging in all directions, at least through a large angular extent, we may represent the disturbance of ether on the point of the retina, produced by the small portion δy of the large wave, by

$$\delta y \times \sin \frac{2\pi}{\lambda} (vt - \xi)$$

or

$$\delta y \times \sin \frac{2\pi}{\lambda} \left\{ vt - f + \frac{a}{2ce} \left(y + \frac{cb}{a}\right)^2 \right\}$$

or

$$\begin{aligned}\sin \frac{2\pi}{\lambda} (vt - f) \cdot \delta y \cos \frac{2\pi}{\lambda} \cdot \frac{a}{2ce} \cdot \left(y + \frac{cb}{a}\right)^2 \\ + \cos \frac{2\pi}{\lambda} (vt - f) \cdot \delta y \sin \frac{2\pi}{\lambda} \cdot \frac{a}{2ce} \cdot \left(y + \frac{cb}{a}\right)^2;\end{aligned}$$

and consequently the disturbance of ether on the point of the retina produced by the whole wave will be

$$\sin \frac{2\pi}{\lambda} (vt - f) \int_y \cos \frac{\pi a}{\lambda ce} \left(y + \frac{cb}{a}\right)^2 + \cos \frac{2\pi}{\lambda} (vt - f) \int_y \sin \frac{\pi a}{\lambda ce} \left(y + \frac{cb}{a}\right)^2.$$

The limits of y in the integral must be the limiting values which determine the extent of the great wave where it leaves the lens under the circumstances assumed, that is, as far as there is no additional cause of retardation of the wave.

But if, by the interposition of any refracting substance with parallel boundaries, a portion of the wave be retarded by the phase R (expressed as an angle), then the expression to be integrated will be

$$\int_y \sin \left\{ \frac{2\pi}{\lambda} \left\{ vt - f + \frac{a}{2ce} \left(y + \frac{cb}{a}\right)^2 \right\} - R \right\}$$

or

$$\sin \frac{2\pi}{\lambda} (vt - f) \int_y \cos \left\{ \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 - R \right\} \\ + \cos \frac{2\pi}{\lambda} (vt - f) \int_y \sin \left\{ \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 - R \right\}$$

or

$$\sin \frac{2\pi}{\lambda} (vt - f) \left\{ \cos R \cdot \int_y \cos \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 + \sin R \cdot \int_y \sin \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 \right\} \\ + \cos \frac{2\pi}{\lambda} (vt - f) \left\{ \cos R \cdot \int_y \sin \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 - \sin R \cdot \int_y \cos \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 \right\},$$

where the limits of y in the integral must be the values which determine the extent of that portion of the great wave which is affected by the interposition of the refracting substance.

Suppose now that a plate of mica or other refracting substance is so placed as to cover a portion of the pupil on that side on which y is considered positive; and suppose that its limits, measured in the same way, are from $y = +g$ to y indefinitely great: suppose also that the limits of the pupil are from $y = -h$ to $y = +h$; then the integral which is independent of R must be taken from $y = -h$ to $y = +g$, and that which depends on R must be taken from $y = +g$ to $y = +h$, and the integrals must be added to obtain the whole disturbance of ether at the point of the retina.

Our expressions then depend entirely on the two integrals $\int_y \cos \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2$ and $\int_y \sin \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2$. For estimating these, we shall refer to FRESNEL's invaluable table of $\int_s \cos \frac{\pi}{2} s^2$ and $\int_s \sin \frac{\pi}{2} s^2$ *. If $s = \sqrt{\frac{2a}{\lambda c e}} \cdot \left(y + \frac{cb}{a} \right)$, it is easily seen that $\int_y \cos \frac{\pi a}{\lambda c e} \left(y + \frac{cb}{a} \right)^2 = \sqrt{\frac{\lambda c e}{2a}} \cdot \int_s \cos \frac{\pi}{2} s^2$, the limiting values of s being found from those of y by the equation $s = \sqrt{\frac{2a}{\lambda c e}} \cdot \left(y + \frac{cb}{a} \right)$. Omitting the constant multiplier $\sqrt{\frac{\lambda c e}{2a}}$ (remarking only that, as it becomes infinite when $a = 0$, and impossible when a is negative, different investigations must then be used); and putting $C(s)$ for $\int_s \cos \frac{\pi}{2} s^2$ and $S(s)$ for $\int_s \sin \frac{\pi}{2} s^2$; and remarking that, as FRESNEL's integrals vanish when $s = 0$, and as the differential coefficients have the same values with the same sign for negative and positive values of s , the integrals must have equal values but with opposite signs for negative and positive values of s , or that $C(-s) = -C(s)$, $S(-s) = -S(s)$; we find that the integral, in the case before us, may be represented as follows:

$$\sin \frac{2\pi}{\lambda} (vt - f) \left\{ C \left(\sqrt{\frac{2a}{\lambda c e}} \cdot h - \frac{cb}{a} \right) + C \left(\sqrt{\frac{2a}{\lambda c e}} \cdot g + \frac{cb}{a} \right) \right\}$$

* Mémoire sur la Diffraction, Mém. de l'Institut, 1821 and 1822.

$$\begin{aligned}
& + \cos \frac{2\pi}{\lambda} (vt - f) \left\{ S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h - \frac{cb}{a} \right) + S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \\
& + \sin \frac{2\pi}{\lambda} (vt - f) \cdot \cos R \left\{ C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right) - C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \\
& + \sin \frac{2\pi}{\lambda} (vt - f) \cdot \sin R \left\{ S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right) - S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \\
& + \cos \frac{2\pi}{\lambda} (vt - f) \cdot \cos R \left\{ S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right) - S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \\
& - \cos \frac{2\pi}{\lambda} (vt - f) \cdot \sin R \left\{ C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right) - C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\}.
\end{aligned}$$

The expression in this general form is rather troublesome. If, however, we suppose a not to be exceedingly small, so that $\sqrt{\frac{2a}{\lambda ce}} \cdot h$ is equal to several units, and if we remark that the values of $C(s)$ and $S(s)$ approach rapidly to the limit $\frac{1}{2}$, it will be seen that (for all values of g which are not very nearly equal to h) we shall commit no sensible error in putting $\frac{1}{2}$ for $S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right)$, $S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h - \frac{cb}{a} \right)$,

$$C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h + \frac{cb}{a} \right), \quad C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot h - \frac{cb}{a} \right).$$

Making this substitution, our integral may be put into this form:

$$\begin{aligned}
& \sin \frac{2\pi}{\lambda} (vt - f) \times \left[\frac{1}{2} + C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) + \cos R \left\{ \frac{1}{2} - C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \right. \\
& \quad \left. + \sin R \left\{ \frac{1}{2} - S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \right] \\
& + \cos \frac{2\pi}{\lambda} (vt - f) \times \left[\frac{1}{2} + S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right. \\
& \quad \left. + \cos R \left\{ \frac{1}{2} - S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} - \sin R \left\{ \frac{1}{2} - C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\} \right].
\end{aligned}$$

The intensity of light being estimated, as is usual in the theory of undulations, by the sum of the squares of the coefficients of $\sin \frac{2\pi}{\lambda} (vt - f)$ and $\cos \frac{2\pi}{\lambda} (vt - f)$, we find the following expression for the intensity of light on the point of the retina:

$$\begin{aligned}
& 1 + 2 \left\{ C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\}^2 + 2 \left\{ S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\}^2 \\
& + \cos R \times \left[1 - 2 \left\{ C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\}^2 - 2 \left\{ S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right\}^2 \right] \\
& + \sin R \times \left[2 C \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) - 2 S \left(\sqrt{\frac{2a}{\lambda ce}} \cdot g + \frac{cb}{a} \right) \right].
\end{aligned}$$

Before entering into the detailed consideration of the numerical value of this expression, we will make a similar investigation for the supposition that the luminous point is too near for distinct vision.

Let the distance of the retina from the lens be $c - a'$. The distance ρ , of a point of the wave whose ordinate is y , from the point of the retina whose ordinate is b , is

$$\rho = \sqrt{(x - a')^2 + (y - b)^2} = \sqrt{c^2 - 2a'x - 2by + a'^2 + b^2} = \sqrt{c^2 - a'^2 + b^2 - 2by + \frac{a'^2}{c}}; \text{ and putting } e^2 = c^2 - a'^2 + b^2, \text{ and expanding as before, this becomes}$$

$$\begin{aligned} \rho &= e - \frac{b}{e}y + \frac{a'^2}{2ce}y^2 \\ &= f + \frac{a'}{2ce}\left(y - \frac{cb}{a'}\right)^2, \end{aligned}$$

where $f = e - \frac{cb^2}{2ea'}$.

The integral which expresses the disturbance of ether at the point of the retina is now

$$\sin \frac{2\pi}{\lambda} (vt - f) \int_y \cos \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2 - \cos \frac{2\pi}{\lambda} (vt - f) \int_y \sin \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2$$

to be taken from $y = -h$ to $y = +g$. And

$$\begin{aligned} &\sin \frac{2\pi}{\lambda} (vt - f) \left\{ \cos R \int_y \cos \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2 - \sin R \int_y \sin \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2 \right\} \\ &- \cos \frac{2\pi}{\lambda} (vt - f) \left\{ \cos R \int_y \sin \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2 + \sin R \int_y \cos \frac{\pi a'}{\lambda ce} \left(y - \frac{cb}{a'}\right)^2 \right\} \end{aligned}$$

to be taken from $y = +g$ to $y = +h$.

Proceeding exactly as before, omitting the constant multiplier $\sqrt{\frac{\lambda ce}{2a'}}$, supposing h to be large in the integral, and estimating the intensity of light on the point of the retina as before, we obtain this expression:

$$\begin{aligned} &1 + 2 \left\{ C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) \right\}^2 + 2 \left\{ S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) \right\}^2 \\ &+ \cos R \times \left[1 - 2 \left\{ C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) \right\}^2 - 2 \left\{ S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) \right\}^2 \right] \\ &+ \sin R \times \left[2 S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) - 2 C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot g - \frac{cb}{a'} \right) \right] \end{aligned}$$

or

$$\begin{aligned} &1 + 2 \left\{ C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) \right\}^2 + 2 \left\{ S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) \right\}^2 \\ &+ \cos R \times \left[1 - 2 \left\{ C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) \right\}^2 - 2 \left\{ S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) \right\}^2 \right] \\ &+ \sin R \times \left[2 C \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) - 2 S \left(\sqrt{\frac{2a'}{\lambda ce}} \cdot \frac{cb}{a'} - g \right) \right]. \end{aligned}$$

This expression is exactly similar to that obtained for the case when the luminous point is too distant for distinct vision, in the following particulars, which we shall find to be very important. First, the general form is the same. Secondly, the argument of the functions C and S has the quantity b with the positive sign in both expressions; and therefore, in both expressions, the argument increases as b increases. We shall also find the following remark to be not without importance; that, in the arguments of the functions in the two expressions, the quantity g enters with different signs.

Our expressions now depend entirely upon the three functions,

$$1 + 2(C(s))^2 + 2(S(s))^2,$$

$$1 - 2(C(s))^2 - 2(S(s))^2,$$

$$2C(s) - 2S(s),$$

which we shall call $A(s)$, $D(s)$, and $E(s)$. Adopting FRESNEL'S values of $C(s)$ and $S(s)$, I have computed the following values of $A(s)$, $D(s)$, and $E(s)$.

s .	$A(s)$.	$D(s)$.	$E(s)$.	s .	$A(s)$.	$D(s)$.	$E(s)$.
0.0	+1.000	+1.000	0.000	2.9	+1.969	+0.031	+0.306
0.1	+1.020	+0.980	+0.199	3.0	+2.227	-0.227	+0.220
0.2	+1.080	+0.920	+0.391	3.1	+2.308	-0.308	-0.039
0.3	+1.180	+0.820	+0.571	3.2	+2.129	-0.129	-0.253
0.4	+1.318	+0.682	+0.728	3.3	+1.869	+0.131	-0.226
0.5	+1.493	+0.507	+0.856	3.4	+1.754	+0.246	+0.019
0.6	+1.700	+0.300	+0.942	3.5	+1.912	+0.088	+0.236
0.7	+1.929	+0.071	+0.976	3.6	+2.176	-0.176	+0.193
0.8	+2.169	-0.169	+0.949	3.7	+2.249	-0.249	-0.064
0.9	+2.401	-0.401	+0.852	3.8	+2.042	-0.042	-0.234
1.0	+2.601	-0.601	+0.685	3.9	+1.809	+0.192	-0.105
1.1	+2.743	-0.743	+0.457	4.0	+1.850	+0.150	+0.157
1.2	+2.802	-0.802	+0.186	4.1	+2.111	-0.111	+0.197
1.3	+2.758	-0.758	-0.093	4.2	+2.221	-0.221	-0.042
1.4	+2.609	-0.609	-0.339	4.3	+2.018	-0.018	-0.208
1.5	+2.371	-0.371	-0.502	4.4	+1.812	+0.189	-0.047
1.6	+2.084	-0.084	-0.545	4.5	+1.930	+0.070	+0.184
1.7	+1.814	+0.186	-0.449	4.6	+2.176	-0.176	+0.103
1.8	+1.630	+0.370	-0.233	4.7	+2.126	-0.126	-0.150
1.9	+1.591	+0.409	-0.043	4.8	+1.870	+0.130	-0.125
2.0	+1.713	+0.287	+0.291	4.9	+1.879	+0.122	+0.131
2.1	+1.957	+0.043	+0.416	5.0	+2.133	-0.133	+0.130
2.2	+2.225	-0.225	+0.363	5.1	+2.132	-0.132	-0.124
2.3	+2.398	-0.398	+0.149	5.2	+1.879	+0.121	-0.115
2.4	+2.385	-0.385	-0.128	5.3	+1.903	+0.097	+0.135
2.5	+2.186	-0.186	-0.322	5.4	+2.149	-0.149	+0.087
2.6	+1.908	+0.092	-0.321	5.5	+2.070	-0.070	-0.150
2.7	+1.719	+0.281	-0.120				
2.8	+1.744	+0.256	+0.153	∞	+2.000	0.000	0.000

For negative values of s , the numerical values of $A(s)$, $D(s)$, and $E(s)$ are the same as for the equal positive values of s : the signs of $A(s)$ and $D(s)$ are the same for the positive and negative values of s , but the signs of $E(s)$ are different.

The first remark which presents itself, in looking at this table, is, that the numbers $D(s)$ and $E(s)$ increase and diminish, and then change signs and increase and diminish, with increasing values of s ; that the maximum of one always coincides nearly with the vanishing point of the other; and that the maximum values are nearly equal in both series (regard being had to the general diminution of the numbers as s increases); in fact, that these numbers may be represented as the cosine and sine of the same arc, the radius being slowly variable. To prove this, let us make $D(s) = G(s) \cdot \cos \phi(s)$, $E(s) = G(s) \sin \phi(s)$, and investigate the values of $G(s)$ and $\phi(s)$ for every value of s in the Table. They are easily found by the formulæ

$$G(s) = \sqrt{\{D(s)^2 + E(s)^2\}}, \quad \tan \phi(s) = \frac{E(s)}{D(s)}$$

In this manner the following Table is formed; in which, for more distinct appreciation of the progress of $\phi(s)$, the differences of $\phi(s)$ are set down.

s .	$G(s)$.	$\phi(s)$.	Difference.	s .	$G(s)$.	$\phi(s)$.	Difference.
0.0	1.000	0 0	11 28	2.9	0.307	$720^\circ + 84 14$	51 29
0.1	1.000	11 28	11 37	3.0	.316	135 43	51 27
0.2	1.000	23 5	11 47	3.1	.311	187 10	54 1
0.3	0.999	34 52	12 0	3.2	.288	241 11	58 56
0.4	.997	46 52	12 29	3.3	.263	300 7	64 15
0.5	.993	59 21	12 54	3.4	.249	$1080^\circ + 4 22$	65 8
0.6	.988	72 15	13 36	3.5	.252	69 30	63 0
0.7	.979	85 51	14 17	3.6	.261	132 30	62 1
0.8	.963	100 8	15 7	3.7	.256	194 31	65 21
0.9	.943	115 15	16 0	3.8	.235	259 52	71 24
1.0	.909	131 15	17 11	3.9	.218	331 16	75 0
1.1	.869	148 26	18 27	4.0	.217	$1440^\circ + 46 16$	72 59
1.2	.822	166 53	20 9	4.1	.226	119 15	71 24
1.3	.762	187 2	22 5	4.2	.225	190 39	74 29
1.4	.696	209 7	24 24	4.3	.209	265 8	80 51
1.5	.622	233 31	27 41	4.4	.195	345 59	83 15
1.6	.552	261 12	31 19	4.5	.198	$1800^\circ + 69 14$	80 23
1.7	.490	292 31	35 14	4.6	.204	149 37	80 23
1.8	.441	327 45	38 18	4.7	.195	230 0	86 15
1.9	.413	$360^\circ + 6 3$	39 12	4.8	.180	316 15	90 58
2.0	.424	45 15	38 49	4.9	.180	$2160^\circ + 47 13$	88 25
2.1	.419	84 4	37 43	5.0	.186	135 38	87 39
2.2	.428	121 47	37 43	5.1	.180	223 17	93 15
2.3	.424	159 30	38 53	5.2	.169	316 32	97 53
2.4	.404	198 23	41 34	5.3	.169	$2520^\circ + 54 25$	95 8
2.5	.372	239 57	46 2	5.4	.173	149 33	95 22
2.6	.335	285 59	50 54	5.5	.166	244 55	
2.7	.309	336 53	53 59				
2.8	0.300	$720^\circ + 30 52$	53 22	∞	.000		

For negative values of s , the numerical values of $G(s)$ and $\phi(s)$ are the same as for equal positive values of s ; the sign of $G(s)$ is always positive, but the sign of $\phi(s)$ is the same as that of s .

The uniformity in the progress of the values, both of $G(s)$ and of $\phi(s)$, is very remarkable; and seems to render it probable that, although the functions $D(s)$ and $E(s)$ have been formed in such different ways from $C(s)$ and $S(s)$, and although $C(s)$ and $S(s)$ are formed in a manner which scarcely permits a simple relation between them, yet some simple expression for $G(s)$ and $\phi(s)$ must exist. This presumption becomes stronger, when we examine the values of s which correspond to the quadrantal values of $\phi(s)$. If we make $\phi(s)$ successively equal to $0, 90^\circ, 180^\circ, 270^\circ$, &c., and take the corresponding values of s , and the squares of those values, we form the following series.

Quadrant of $\phi(s)$.	Value of s .	Value of s^2 .	Quadrant of $\phi(s)$.	Value of s .	Value of s^2 .
0	0.00	0.00	16	3.94	15.5
1	0.73	0.53	17	4.06	16.5
2	1.27	1.61	18	4.18	17.5
3	1.63	2.66	19	4.31	18.6
4	1.88	3.53	20	4.42	19.6
5	2.12	4.50	21	4.53	20.6
6	2.36	5.60	22	4.64	21.5
7	2.57	6.60	23	4.75	22.5
8	2.74	7.50	24	4.85	23.5
9	2.91	8.49	25	4.95	24.5
10	3.09	9.5	26	5.06	25.5
11	3.25	10.6	27	5.15	26.6
12	3.40	11.6	28	5.24	27.5
13	3.53	12.5	29	5.34	28.5
14	3.67	13.5	30	5.44	29.6
15	3.81	14.5			

The values of s^2 corresponding to the successive quadrants of $\phi(s)$ increase pretty uniformly every time by 1, except in the first instance, where the increase is 0.5. This interruption of the law is not without analogues in Physical Optics. I may mention the expression for the intensity of light produced by a grating before a lens, namely $\left(\frac{\sin \pi \theta}{\sin \theta}\right)^2$, of which the first and greatest maximum occurs when $\theta = 0$, and the succeeding maxima occur nearly when $\theta = \frac{\pi}{2\pi}, \frac{3\pi}{2\pi}, \frac{5\pi}{2\pi}$, &c.

The small irregularities in the progress of these various numbers may probably arise, as I think, from irregularities in FRESNEL's calculation of the original integrals. Several years ago I verified a portion of FRESNEL's table; and though the agreement of my numbers with FRESNEL's was sufficiently close to show that the numbers might be used with perfect safety, yet there were some small discordances which seemed to indicate that a complete recalculation might be useful.

Adopting now for $1 - 2(C(s))^2 - 2(S(s))^2$ and $2C(s) - 2S(s)$, the expressions $G(s) \cos \phi(s)$ and $G(s) \sin \phi(s)$, and observing that $1 + 2(C(s))^2 + 2(S(s))^2 = 2 - G(s) \cos \phi(s)$, the expression for the intensity of light, on the point of the re-

tina whose ordinate is b , becomes, in the case in which the eye is too far from the luminous point to see it distinctly,

$$\begin{aligned} & 2 - G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \cdot \cos \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \\ & + G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \cdot \cos R \cdot \cos \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \\ & + G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \cdot \sin R \cdot \sin \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \\ & = 2 - G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \cdot \cos \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \\ & + G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) \cdot \cos \left\{ \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} + g} \right) - R \right\}. \end{aligned}$$

And similarly, in the case in which the eye is too near to see distinctly, the expression for the intensity is

$$\begin{aligned} & 2 - G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} - g} \right) \cdot \cos \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} - g} \right) \\ & + G \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} - g} \right) \cdot \cos \left\{ \phi \left(\sqrt{\frac{a}{\lambda c e} \cdot \frac{c b}{a} - g} \right) - R \right\}. \end{aligned}$$

It must be remarked that, in every part of the investigation, we suppose the square root to be taken with the positive sign.

To present to the eye a representation of the value of $G(s) \cos \phi(s)$, upon which the whole of our computations now depend, I have constructed the curve, Plate VIII. fig. 1., in which the abscissa represents the value of s , and the ordinate represents the value of $G(s) \cos \phi(s)$. The curve corresponding to the value of $G(s) \cos \phi(s) - R$ may be sufficiently well inferred from this, by conceiving the whole curve to be pushed on, not through the same space in all parts, but in different parts through different spaces, bearing always the same proportion to the length of one of the waves which it bears to 360° . Thus $G(s) \cos \phi(s) - 90^\circ$ is represented by the curve in fig. 2.

From an inspection of fig. 1, the following points are easily ascertained. First, that the variations of intensity of light, which are represented by $G(s) \cdot \cos \phi(s)$, are so small when s is large, that they might on that account alone be rejected. Secondly, that if the intensities of a great number of non-interfering streams of light be aggregated, the origin of s for each of the streams having a different position, but the intermediate distances of these origins being small: the variations of intensity near the origins of s may all sensibly coincide so as to produce a set of strong alternations of light and dark in the aggregate; while at the places where s is large, the small distances of the origins and the corresponding displacement of the waves of the curve will be sufficiently great to cause the elevated parts of one curve to answer to the depressed parts of another, &c., or the strong light of one stream to be mingled with

the weak light of another; and thus the alternations of light and dark will be visible only near the origins of s . Thirdly, that if the origins of s in the non-interfering streams of light do coincide, but if the values of λ are very different, the values of s for the same value of b (expressed by $\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g}$) may, when b is large, differ very much for the different values of λ , and thus the strong light of one stream will be mingled with the weak light of another: and here also the alternation of light and dark will be visible only near the origins of s . I will now proceed with practical applications of our formulæ.

1. Suppose that heterogeneous light issues from a point or a narrow line, and is viewed by an eye too distant to see it distinctly: a thin plate of mica, with its edge parallel to the line, is gradually brought across the pupil of the eye: to describe the appearance of the line.

The formula is

$$2 - G \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) \cdot \cos \phi \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) \\ + G \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) \cos \left\{ \phi \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) - R \right\};$$

and the aggregate of all the values of this expression for the different values of λ is to be taken. Now the last term may be rejected at once. For the values of R will vary very much, perhaps to the extent of many multiples of 360° , for the differently coloured rays; and therefore, in the aggregate, the expressions

$$\cos \left\{ \phi \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) - R \right\}$$

which are added together, will have had all values, positive and negative. The expression is therefore

$$2 - G \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right) \cos \phi \left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cb}{a} + g} \right).$$

The alternations of light represented by this, for the reasons above mentioned, will be sensible only where $\frac{cb}{a} + g$ is small, that is, where b differs little from $-\frac{ag}{c}$. If then the edge of the mica is on the *right* side of the centre of the pupil, the bands of light will be on the *left* side of the centre of the confused image on the retina, or will give to the mind the perception of bands of light on the *right* side of the object viewed: and therefore, upon moving the plate of mica, the bands will appear to move in the same direction. Moreover, the band which is most conspicuous, because its coefficient of the variable part is largest, because it is unaffected by the variation of λ , and because the other bands are ranged symmetrically on both sides, is that for which $\frac{cb}{a} + g$ is 0, and for this the expression of intensity for every colour is $2 - G(0) \cos \phi(0) = 2 - 1 = 1$, which is its minimum value. Hence there will be seen a central dark

band strongly marked, with bright and dark bands on each side faintly marked. And the whole of these phenomena will be independent of the thickness of the mica (within wide limits). The reader may very easily verify these conclusions by experiment; and the whole will be found strictly in agreement with observation.

If the eye had been supposed too near to see the line of light distinctly, the investigation would have been precisely the same, but the place where the bands are sensible would have been determined by making $\frac{cb}{a} - g$ small, or b nearly equal to $+\frac{dg}{c}$; from which it will appear that, upon moving the plate of mica, the bands will appear to move in the opposite direction; which agrees with observation.

2. Suppose that the linear origins of the various kinds of homogeneous light are separated, either by prism-refraction, or by the diffraction of a grating, or in any other way which arranges the colours in an order corresponding to the order of the values of λ ; suppose that the eye is too distant to see the lines of colour distinctly; a thin plate of mica, with its edge parallel to the lines, is gradually brought across the pupil of the eye: to describe the appearance of the spectrum.

First, suppose the red end of the spectrum to be on the same side as the plate of mica, or on that side on which b and g are considered positive.

Let k be the ordinate measured from a fixed point on the retina to the centre of the confused image of any one colour (k therefore is a function of λ); and let l be the ordinate, measured from the same fixed point, of any point of which the intensity of light is to be ascertained. Then $k + b = l$, or $b = l - k$. Substituting this in the general expression for intensity, it becomes

$$2 - G \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right) \cdot \cos \phi \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right) \\ + G \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right) \cdot \cos \left\{ \phi \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right) - R \right\}.$$

Now the second term of this expression may at once be neglected, without consideration of the position of the spectrum. For as k is a function of λ , and as the spectral separation is considerable, $\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{ck}{a}$ will vary rapidly with λ , and therefore the angle $\phi \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right)$ may have all the values included in several circumferences, for the variation of λ included in those rays which fall on the same point l ; and the positive and negative values of the cosine will sensibly destroy each other.

With regard to the third term, it must be remarked that, in the image formed upon the retina, the blue end of the spectrum is on the same side as the plate of mica, or that k is greatest for the most refrangible rays, and therefore

$$\phi \left(\sqrt{\frac{2a}{\lambda ce}} \cdot \frac{cl}{a} + g - \frac{ck}{a} \right)$$

is least for the most refrangible rays. Moreover, R is greatest, or $-R$ is least, for the most refrangible rays. Hence the effect of the addition of the term $-R$ is to make the variation of the argument of the cosine still more rapid for the variation of λ , and the positive and negative values of the cosine will therefore destroy each other, or the third term may be neglected.

The expression for intensity is, therefore, reduced to its first term 2, or there are no visible bands in the spectrum.

Secondly, suppose the blue end of the spectrum to be on the same side as the plate of mica.

The second term of the expression may be neglected, as before. But with regard to the third term, the circumstances are entirely different. For k is now least for the most refrangible rays (the blue end of the spectrum formed on the retina being on the side opposite to the mica), and therefore $\phi\left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cl}{a} + g - \frac{ck}{a}}\right)$ is greatest for the most refrangible rays; and therefore the chromatic variations of the different parts of the argument $\phi\left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cl}{a} + g - \frac{ck}{a}}\right) - R$ have a tendency to destroy each other. And by proper selection of the thickness of the piece of mica, the chromatic variations of R (for the colours which fall upon the same point of the retina) may be the same as the chromatic variations of $\phi\left(\sqrt{\frac{2a}{\lambda ce} \cdot \frac{cl}{a} + g - \frac{ck}{a}}\right)$, for those values of the function which make the bands most brilliant. In this case, then, the bands produced by all the neighbouring colours will be aggregate in intensity, and therefore strong bands will be seen on the spectrum.

With regard to the place at which any bright or dark band is seen, as depending on the place of the edge of the mica; that is, with regard to the value of l for one of these bands, as depending on g ; it will be evident that the intensity (whether strongest or weakest) will be preserved the same by keeping $\frac{cl}{a} + g$ the same; that is, there will be a band of the same character so long as l varies in the same degree as $\frac{ag}{c}$, but in the opposite direction; that is, the band upon the retina will shift in the direction opposite to the shift of the mica, or will appear to the mind to shift in the same direction as the mica. But this shift will be small when a is small.

3. Suppose that the eye is too near to see the lines of colour distinctly, and that other circumstances are the same as in the second problem.

The expression for intensity in this case is

$$2 - G\left(\sqrt{\frac{2a'}{\lambda ce} \cdot \frac{cl}{a'} - g - \frac{ck}{a'}}\right) \cdot \cos \phi\left(\sqrt{\frac{2a'}{\lambda ce} \cdot \frac{cl}{a'} - g - \frac{ck}{a'}}\right) \\ + G\left(\sqrt{\frac{2a'}{\lambda ce} \cdot \frac{cl}{a'} - g - \frac{ck}{a'}}\right) \cdot \cos \left\{ \phi\left(\sqrt{\frac{2a'}{\lambda ce} \cdot \frac{cl}{a'} - g - \frac{ck}{a'}}\right) - R \right\}.$$

The investigation of the effect of the different terms may be conducted in the very same words as in the second problem, and the result is precisely the same; namely, that when the red end of the spectrum is on the same side as the mica, no bands are produced; but that when the blue end of the spectrum is on the same side as the mica, and the thickness of the mica is properly adjusted, the bands produced by the neighbouring colours will correspond, or nearly so, and strong bands will therefore be produced in the aggregate effect on the eye.

With regard to the place at which any bright or dark band is seen, as depending on the place of the edge of the mica, the intensity will now be preserved the same by keeping $\frac{e}{d} - g$ the same; that is, a band of the same character will be preserved by making the variations of l equal to those of $\frac{d}{e}g$, and in the same direction; or the bands upon the retina will shift in the same direction as the shift of the mica, and the mind will therefore perceive bands to shift in the opposite direction to the shift of the mica.

To exhibit more distinctly to the eye the cause of the annihilation of the bands when the red end of the external spectrum or the blue end of the spectrum on the retina is on the same side as the mica, and the cause of the formation of the bands when the blue end of the external spectrum or the red end of the spectrum on the retina is on the same side as the mica, I have constructed diagrams (figs. 3, 4, 5, 6, 7,) founded on the following calculations. The Table below contains computed values of $2 - G(s) \cdot \cos \phi(s) + G(s) \cdot \cos \phi(s) - R$ for all the values of s which are likely to produce sensible effects in the result; and for the values of R , $0, 30^\circ, 60^\circ, 90^\circ, 120^\circ, 150^\circ, 180^\circ, 210^\circ, 240^\circ, 270^\circ, 300^\circ, 330^\circ$. These of course apply also to the values of R , $2n\pi, 2n\pi + 30^\circ, 2n\pi + 60^\circ$, &c.

Table of the values of $2 - G(s) \cdot \cos \phi(s) + G(s) \cdot \cos \{\phi(s) - R\}$.

	Values of R.												
s	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	
-4.2	2.000	2.050	2.146	2.263	2.368	2.433	2.442	2.392	2.296	2.179	2.074	2.009	
-4.1	2.000	1.917	1.885	1.914	1.995	2.108	2.222	2.305	2.337	2.308	2.227	2.114	
-4.0	2.000	1.902	1.789	1.693	1.639	1.642	1.700	1.798	1.911	2.007	2.061	2.058	
-3.9	2.000	2.037	1.995	1.914	1.804	1.696	1.617	1.591	1.623	1.704	1.814	1.922	
-3.8	2.000	2.132	2.222	2.273	2.263	2.193	2.084	1.962	1.862	1.811	1.821	1.891	
-3.7	2.000	2.066	2.181	2.313	2.428	2.496	2.498	2.432	2.317	2.185	2.070	2.002	
-3.6	2.000	1.927	1.921	1.984	2.098	2.233	2.352	2.425	2.431	2.368	2.254	2.119	
-3.5	2.000	1.870	1.752	1.676	1.663	1.718	1.824	1.954	2.072	2.148	2.161	2.106	
-3.4	2.000	1.960	1.862	1.735	1.613	1.520	1.508	1.548	1.646	1.773	1.895	1.978	
-3.3	2.000	2.097	2.132	2.097	2.000	1.868	1.738	1.641	1.606	1.641	1.738	1.870	
-3.2	2.000	2.145	2.288	2.391	2.427	2.386	2.378	2.133	1.990	1.887	1.851	1.892	
-3.1	2.000	2.060	2.187	2.347	2.496	2.595	2.616	2.556	2.429	2.269	2.120	2.021	
-3.0	2.000	1.921	1.923	2.006	2.149	2.313	2.454	2.533	2.531	2.448	2.305	2.141	
-2.9	2.000	1.843	1.720	1.664	1.689	1.790	1.938	2.095	2.218	2.274	2.249	2.148	
-2.8	2.000	1.890	1.739	1.590	1.482	1.444	1.488	1.598	1.749	1.898	2.006	2.044	
-2.7	2.000	2.026	1.966	1.840	1.682	1.534	1.438	1.412	1.472	1.598	1.756	1.904	
-2.6	2.000	2.149	2.233	2.230	2.141	1.989	1.816	1.667	1.583	1.586	1.675	1.827	
-2.5	2.000	2.186	2.372	2.508	2.558	2.508	2.372	2.186	2.000	1.864	1.814	1.864	
-2.4	2.000	2.117	2.303	2.512	2.687	2.781	2.770	2.653	2.467	2.258	2.083	1.989	
-2.3	2.000	1.980	2.071	2.249	2.468	2.668	2.796	2.816	2.725	2.547	2.328	2.128	
-2.2	2.000	1.848	1.797	1.861	2.023	2.238	2.450	2.602	2.653	2.589	2.427	2.212	
-2.1	2.000	1.786	1.618	1.540	1.574	1.711	1.914	2.128	2.296	2.374	2.340	2.203	
-2.0	2.000	1.821	1.601	1.412	1.304	1.304	1.426	1.605	1.825	2.014	2.122	2.122	
-1.9	2.000	1.923	1.759	1.548	1.348	1.213	1.181	1.257	1.423	1.634	1.834	1.969	
-1.8	2.000	2.071	2.020	1.866	1.647	1.425	1.260	1.189	1.240	1.394	1.613	1.835	
-1.7	2.000	2.203	2.300	2.267	2.112	1.878	1.628	1.423	1.328	1.361	1.516	1.750	
-1.6	2.000	2.284	2.514	2.639	2.599	2.430	2.168	1.884	1.654	1.529	1.569	1.738	
-1.5	2.000	2.301	2.619	2.871	2.989	2.941	2.742	2.441	2.123	1.871	1.753	1.801	
-1.4	2.000	2.252	2.598	2.948	3.206	3.304	3.318	2.966	2.620	2.270	2.012	1.914	
-1.3	2.000	2.150	2.461	2.851	3.217	3.460	3.516	3.366	3.055	2.665	2.299	2.056	
-1.2	2.000	2.015	2.240	2.615	3.041	3.402	3.604	3.589	3.364	2.989	2.563	2.202	
-1.1	2.000	1.874	1.979	2.288	2.719	3.157	3.486	3.612	3.507	3.198	2.767	2.329	
-1.0	2.000	1.740	1.709	1.918	2.309	2.778	3.202	3.462	3.493	3.284	2.893	2.424	
-0.9	2.000	1.626	1.461	1.548	1.863	2.323	2.802	3.176	3.341	3.254	2.939	2.479	
-0.8	2.000	1.548	1.263	1.221	1.433	1.842	2.338	2.790	3.075	3.117	2.905	2.496	
-0.7	2.000	1.496	1.113	0.946	1.042	1.373	1.852	2.350	2.733	2.900	2.804	2.473	
-0.6	2.000	1.490	1.036	0.759	0.734	0.969	1.400	1.910	2.364	2.641	2.666	2.431	
-0.5	2.000	1.504	1.006	0.639	0.500	0.628	0.986	1.482	1.980	2.347	2.486	2.358	
-0.4	2.000	1.545	1.029	0.590	0.347	0.364	0.636	1.091	1.607	2.046	2.289	2.272	
-0.3	2.000	1.604	1.095	0.609	0.275	0.184	0.360	0.756	1.265	1.751	2.085	2.176	
-0.2	2.000	1.681	1.200	0.688	0.281	0.087	0.160	0.479	0.960	1.472	1.879	2.073	
-0.1	2.000	1.769	1.338	0.821	0.358	0.072	0.040	0.271	0.702	1.219	1.682	1.968	
0.0	2.000	1.866	1.500	1.000	0.500	0.134	0.000	0.134	0.500	1.000	1.500	1.866	
+0.1	2.000	1.968	1.682	1.219	0.702	0.271	0.040	0.072	0.358	0.821	1.338	1.769	
+0.2	2.000	2.073	1.879	1.472	0.950	0.479	0.160	0.087	0.281	0.688	1.200	1.681	
+0.3	2.000	2.176	2.085	1.751	1.265	0.756	0.360	0.184	0.275	0.609	1.095	1.604	
+0.4	2.000	2.272	2.289	2.046	1.507	1.091	0.636	0.364	0.479	0.960	1.472	1.879	
+0.5	2.000	2.358	2.486	2.347	1.980	1.482	0.986	0.628	0.500	0.639	1.006	1.504	
+0.6	2.000	2.431	2.666	2.641	2.364	1.910	1.400	0.969	0.734	0.759	1.036	1.490	
+0.7	2.000	2.473	2.804	2.900	2.733	2.350	1.852	1.373	1.042	0.946	1.113	1.496	
+0.8	2.000	2.496	2.905	3.117	3.075	2.790	2.338	1.842	1.433	1.221	1.263	1.548	
+0.9	2.000	2.479	2.939	3.234	3.341	3.176	2.802	2.323	1.863	1.548	1.461	1.626	
+1.0	2.000	2.424	2.893	3.284	3.493	3.462	3.202	2.778	2.309	1.918	1.709	1.740	
+1.1	2.000	2.329	2.767	3.198	3.507	3.612	3.486	3.157	2.719	2.288	1.979	1.874	
+1.2	2.000	2.202	2.563	2.989	3.364	3.589	3.604	3.402	3.041	2.615	2.240	2.015	
+1.3	2.000	2.056	2.299	2.665	3.055	3.366	3.516	3.460	3.217	2.851	2.461	2.150	

TABLE. (Continued.)

s	Values of R.											
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
+1.4	2.000	1.914	2.012	2.270	2.620	2.966	3.318	3.304	3.206	2.948	2.598	2.252
+1.5	2.000	1.801	1.753	1.871	2.123	2.441	2.742	2.941	2.989	2.871	2.619	2.301
+1.6	2.000	1.738	1.569	1.529	1.654	1.884	2.168	2.430	2.599	2.639	2.514	2.284
+1.7	2.000	1.750	1.516	1.361	1.328	1.425	1.628	1.878	2.112	2.267	2.300	2.203
+1.8	2.000	1.835	1.613	1.394	1.240	1.189	1.260	1.425	1.647	1.866	2.020	2.071
+1.9	2.000	1.969	1.834	1.634	1.423	1.257	1.181	1.213	1.348	1.548	1.759	1.925
+2.0	2.000	2.122	2.122	2.014	1.825	1.605	1.426	1.304	1.304	1.412	1.601	1.821
+2.1	2.000	2.203	2.340	2.374	2.296	2.128	1.914	1.711	1.574	1.540	1.618	1.786
+2.2	2.000	2.212	2.427	2.589	2.653	2.602	2.450	2.238	2.023	1.861	1.797	1.848
+2.3	2.000	2.128	2.328	2.547	2.725	2.816	2.796	2.668	2.468	2.249	2.071	1.980
+2.4	2.000	1.989	2.083	2.258	2.467	2.653	2.770	2.781	2.687	2.512	2.303	2.117
+2.5	2.000	1.864	1.814	1.964	2.000	2.185	2.372	2.508	2.558	2.508	2.372	2.186
+2.6	2.000	1.827	1.675	1.586	1.583	1.667	1.816	1.989	2.141	2.230	2.233	2.149
+2.7	2.000	1.904	1.756	1.598	1.472	1.412	1.438	1.534	1.682	1.840	1.966	2.026
+2.8	2.000	2.044	2.006	1.898	1.749	1.598	1.488	1.444	1.482	1.590	1.739	1.890
+2.9	2.000	2.148	2.249	2.274	2.218	2.095	1.938	1.790	1.659	1.664	1.730	1.843
+3.0	2.000	2.241	2.305	2.448	2.531	2.533	2.454	2.313	2.149	2.006	1.923	1.921
+3.1	2.000	2.021	2.120	2.269	2.429	2.556	2.616	2.595	2.496	2.347	2.187	2.060
+3.2	2.000	1.892	1.851	1.887	1.990	2.133	2.378	2.386	2.427	2.391	2.288	2.145
+3.3	2.000	1.870	1.738	1.641	1.606	1.641	1.738	1.868	2.000	2.097	2.132	2.097
+3.4	2.000	1.978	1.895	1.773	1.646	1.548	1.508	1.530	1.613	1.735	1.862	1.960
+3.5	2.000	2.106	2.161	2.148	2.072	1.954	1.824	1.718	1.663	1.676	1.752	1.870
+3.6	2.000	2.119	2.254	2.368	2.431	2.425	2.352	2.233	2.098	1.984	1.921	1.927
+3.7	2.000	2.002	2.070	2.185	2.317	2.432	2.498	2.496	2.428	2.313	2.181	2.066
+3.8	2.000	1.891	1.821	1.811	1.862	1.962	2.084	2.193	2.263	2.273	2.232	2.122
+3.9	2.000	1.922	1.814	1.704	1.623	1.591	1.617	1.696	1.804	1.914	1.995	2.027
+4.0	2.000	2.058	2.061	2.007	1.911	1.798	1.700	1.642	1.639	1.693	1.789	1.902
+4.1	2.000	2.114	2.227	2.308	2.337	2.305	2.222	2.108	1.995	1.914	1.885	1.917
+4.2	2.000	2.009	2.074	2.179	2.296	2.392	2.442	2.433	2.368	2.263	2.146	2.050

Fig. 3. contains a graphical representation of the variations of intensity corresponding to these twelve different values of R, the elevation of the curve above its straight line representing the intensity, as given in the Table; the curve at the bottom represents the aggregate in the same manner (the sums of the ordinates being divided by twelve): this figure corresponds to the case of the first problem, excepting that, as no variation is made in the value of λ for the different curves, (which ought to be done, because s here = $\sqrt{\frac{qa}{\lambda ce} \cdot \frac{cb}{a} + g}$), the destruction of the bands in receding from the centre is not properly represented; the central bands however are properly represented. Fig. 4. contains a representation of the effect of shifting the central origin of each set of bands by a space proportionate to R, so that the shift 1.8 in the values of s corresponds to 360° of R, the direction of the shift being that produced by placing the red end of the spectrum next to the mica; the first curve at the bottom represents the aggregate in the same manner (the sum of the ordinates being divided by twelve); the second curve represents the aggregate, supposing twenty-four curves taken, the shift of s in the twenty-fourth being double of that in the twelfth; the de-

struction of bands is here, as to sense, complete, although the shift of s is the same in amount as that which (when taken the opposite way) produces strong bands. Fig. 5. contains a representation of the effect of shifting the bands in the direction of the shift produced by placing the blue end of the spectrum next to the mica, so that the shift 1.2 in the value of s corresponds to 360° of R . Fig. 6. has the same with the shift 1.8 in the value of s corresponding to 360° of R ; and fig. 7. has the same with the shift 2.4 in the value of s corresponding to 360° of R . Each of these figures has at the bottom a curve showing the effect of the aggregation, supposing twelve curves taken (the sum of the ordinates being divided by twelve), and another showing the effect supposing twenty-four curves taken (the sum of the ordinates being divided by twenty-four), the value of R for the twenty-fourth being double of that for the twelfth. The intensity of the bands in the result is here seen well.

It must be remarked that no sensible error is produced here by making no variation in the value of λ . For the different kinds of light which are mingled are not those from all parts of the spectrum, but those from parts of the spectrum of a very limited extent; and the properties of the difference of quality of the different rays enter, not immediately in consequence of the variation of λ , but in consequence of the variation of R .

It is also to be remarked that strong bands are produced as well in fig. 5. as in fig. 7, although in the former there is a shift of 1.2 in the value of s corresponding to 360° of R , and in the latter a shift of 2.4 in the value of s corresponding to 360° of R . It appears therefore that, with the same spectrum, considerable latitude in the thickness of the mica is allowable, or considerable latitude in the degree to which the spectrum is viewed out of focus. For the same reason, the same plate of mica, which exhibits bands in the spectrum formed by a prism, may also exhibit bands in the spectrum formed by a grating upon a lens or by reflection from a striated surface, though the proportionate degree of separation of the colours, in different parts of the spectrum, is exceedingly different in these cases.

The intervals of the bands will, however, always be approximately determined by certain numerical changes in the value of R , and there will, therefore, always be *nearly* the same number of bands on the spectrum, and this number will always be *nearly* the same as the number of bands remarked by Mr. TALBOT when the spectrum is seen distinctly. The bands, therefore, will generally become broader as the spectrum becomes broader, that is, as the eye (supposed at first too far off for distinct vision) approaches to the position of distinct vision. It may, however, happen that, as a becomes small, the changes in the value of s will not nearly correspond to those of R , and therefore, in a position intermediate to that at which these bands and that at which Mr. TALBOT's bands are clearly seen, no bands whatever may be visible.

In the whole of the special conclusions deduced from the theory, the agreement with observation is complete. I wish it to be clearly understood that I confine this statement to the general appearance of the phenomena, for measures are yet

wanting in every part; and some of them, depending, as they must, on the variable state of the eye as to focal adjustment during the observation, cannot be obtained with ease or certainty.

The train of phenomena and their related theory may be considered remarkable: in the first place for the apparent obscurity of the explanation, which was sufficient to induce an experienced philosopher to ascribe the appearances to a new property of light; in the next place for the unexpected simplicity of the relation between the numbers which occur in the investigation, which relation contributes materially to facilitate the understanding of the results deduced from them; and lastly, I may perhaps add, for the completeness of the explanation which the phenomenon receives from the undulatory theory.

*Royal Observatory, Greenwich,
May 30, 1840.*

Numerical values of the ordinates of the curves in figures 4, 5, 6, and 7, representing $\frac{1}{12}$ th part of the aggregate of the values of $2 - G(s) \cdot \cos \phi(s) + G(s) \cdot \cos(\phi(s) - R)$ for 12 values of R ; and also, of the curves representing $\frac{1}{24}$ th part of the aggregate of the values for 24 values of R : for values of s increasing 0.1 at each step.

For Figure 4.				For Figure 5.				For Figure 6.				For Figure 7.			
One twelfth part for 12 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twelfth part for 12 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.	One twenty-fourth part for 24 values of R . Continued.
2.130	2.130	2.077	1.915	1.987	1.170	2.109	1.717	2.018	0.784	2.207	1.434	2.046	0.983	1.991	1.502
2.123	2.142	2.071	1.906	1.996	0.987	2.115	1.765	2.016	0.755	2.293	1.369	2.057	1.121	1.785	1.582
2.108	2.131	2.069	1.898	2.020	0.855	2.073	1.816	2.006	0.784	2.346	1.356	2.057	1.303	1.680	1.680
2.069	2.112	2.050	1.892	2.043	0.776	1.994	1.851	1.997	0.872	2.381	1.338	2.042	1.513	1.582	1.785
2.030	2.091	2.038	1.881	2.066	0.749	1.914	1.858	2.014	1.016	2.384	1.471	2.022	1.737	1.502	1.891
2.010	2.071	2.023	1.896	2.054	0.776	1.853	1.831	2.048	1.210	2.352	1.583	2.002	1.956	1.448	1.992
1.982	2.053	2.004	1.906	2.024	0.855	1.850	1.776	2.081	1.447	2.282	1.723	1.983	2.155	1.425	2.093
1.954	2.038	1.983	1.920	1.974	0.987	1.906	1.699	2.065	1.711	2.174	1.878	1.971		1.433	
1.922	2.024	1.964	1.935	1.936	1.170	2.020	1.637	2.075	1.987	2.031	2.034	1.968		1.475	
1.886	2.012	1.949	1.949	1.948	1.400	2.179	1.619	2.045	2.253	1.878	2.174	1.987		1.554	
1.845	2.007	1.935	1.964	2.026	1.609	2.302	1.672	2.000	2.484	1.723	2.292	2.026		1.666	
1.802	2.013	1.920	1.983	2.142	1.964	2.514	1.809	1.957	2.657	1.583	2.353	2.065		1.804	
1.760	2.025	1.907	2.004	2.231	2.265	2.599	2.013	1.926	2.754	1.471	2.384	2.175		1.956	
1.721	2.036	1.896	2.023	2.324	2.546	2.580	2.245	1.915	2.766	1.353	2.381	2.264		2.110	
1.681	2.038	1.891	2.038	2.127	2.777	2.452	2.452	1.921	2.605	1.356	2.346	2.347		2.251	
1.671	2.031	1.892	2.050	1.944	2.926	2.245	2.580	1.964	2.571	1.369	2.293	2.421		2.369	
1.664	2.031	1.898	2.069	1.761	3.066	2.013	2.599	2.083	2.396	1.434	2.207	2.488		2.462	
1.671	2.018	1.906	2.071	1.652	3.086	1.808	2.514	2.227	2.227	1.549	2.137	2.519		2.513	
1.691		1.915		1.676	2.907	1.672	2.362	2.306		1.706		2.530		2.530	
1.722		1.922		1.838	2.411	1.619	2.182	2.571		1.890		2.595		2.512	
1.760		1.934		2.104	2.104	1.637	2.020	2.605		2.071		2.470		2.462	
1.802		1.936		2.411	1.838	1.699	1.906	2.766		2.239		2.317		2.369	
1.846		1.942		2.698	1.676	1.776	1.850	2.754		2.371		2.155		2.251	
1.886		1.948		2.980	1.652	1.831	1.855	2.657		2.455		1.956		2.110	
1.922		1.952		2.966	1.761	1.858	1.913	2.484		2.484		1.727		1.956	
1.954		1.954		2.926	1.944	1.851	1.994	2.253		2.455		1.513		1.804	
1.982		1.952		2.777	2.127	1.816	2.073	1.987		2.371		1.303		1.666	
2.010		1.948		2.546	2.233	1.766	2.115	1.711		2.239		1.121		1.554	
2.030		1.942		2.284	2.231	1.717	2.109	1.447		2.071		0.983		1.475	
2.069		1.936		1.964	2.142	1.682	2.073	1.210		1.890		0.894		1.433	
2.107		1.934		1.689		1.669		1.016		1.706		0.866		1.425	
2.135		1.922		1.400		1.682		0.872		1.540		0.894		1.447	

XIII. *On the Nervous System.* By Sir CHARLES BELL, F.R.S. &c.

Received February 24,—Read April 2, 1840.

TWENTY years have passed since the Society honoured me by printing my first paper on the functions of the nervous system. It is thirty years since I circulated a short essay, in which the idea of the new principle which has guided me in my inquiries into this subject was pointed out. The Society will acknowledge that since that time, investigations into the nervous system have been prosecuted with a success strongly in contrast with that attending the inquiries during the long period of some hundred years, in which a false hypothesis had satisfied the minds of the medical profession, and chained down physiologists in inactivity.

In 1821 I had made so much progress in these investigations, that I was encouraged to present my first paper to the Society, as no longer the expression of mere opinions founded on experiments too delicate to be generally appreciated, but demonstrations of substantial facts, easily proved to be correct, and such as the Society has always sought to encourage. After the principle had been once established by anatomy and experiment, that the nerves possess distinct functions in correspondence with their origins from the brain and spinal marrow, time and opportunity were alone wanting for collecting the pathological facts which were to give importance to the observations in these early papers. Those facts I am now desirous of placing before the Society, to complete the subject as far as regards my own labours.

First in regard to

The Spinal Nerves.

In the earliest part of my investigations I performed experiments on the roots of these nerves. I exposed the spinal marrow, separated the distinct roots, and found that the anterior root on being irritated excited motion, while the posterior root did not excite the muscles. By inference, and by comparing the spinal nerves with those of the encephalon, I was at length led to conclude that the anterior root is provided for motion, and the posterior for sensation; and that the spinal nerves, instead of being common nerves, are in truth combined of roots, one of which gives motion and the other sensation.

Many instances have presented themselves in the prosecution of this subject, to show that, until directed by a knowledge of function, we are inattentive to facts of daily occurrence. To take an example, since I had reason to conclude that the columns of the spinal marrow, and the roots arising from them, were distinct in func-

tion, I have met with no instance of disease in the bodies of the vertebræ attended with paraplegia, in which the muscular power of the limbs has not been the first affected: in all, the defect of motion has been greater than the diminution of sensibility; in some, the motion of the limbs has been lost, whilst the sensibility has been exquisitely acute.

These facts, it is now obvious, are to be accounted for by the motor roots of the spinal nerves being more directly exposed to the influence of the inflammation seated in the bodies of the vertebræ, than the posterior roots of sensation, which arise more remote from the disease.

In a case now before me, there is disease affecting the bodies of the vertebræ of the neck; the arms hang powerless, whilst the sensibility is perfect; and the patient walks stoutly. By looking to the roots of the great nerves of the axillary plexus, in the dead body, the cause of this is manifest; we see that the motor roots cover the spinal marrow, and that, whilst they protect the body of the spinal marrow, they are exposed themselves, by their proximity, to participate in the inflammation of the bone. When a section of the spine and sheath of the spinal marrow is made, especially in the neck or in the loins, it is observed that not only do the anterior roots of the nerves protect the column of the spinal marrow from which they arise, but these roots, together with the *ligamenta denticulata*, whilst they are themselves exposed to the influence of disease in the bodies of the vertebræ, guard the posterior column and sensitive roots. If the inflammation or morbid influence, in this case, had penetrated to the spinal marrow, and had paralysed the muscles of the upper extremities, by affecting that organ, the muscles of the lower extremities would have suffered equally with those of the upper.

The spinal marrow, properly speaking, terminates at the second lumbar vertebra: but the anterior roots of the nerves forming the *cauda equina*, cover and protect the posterior roots from the influence of disease in the bodies of the vertebræ.

The following occurrence will be regarded with interest in connexion with this subject. Plate IX. exhibits a tumour which engaged the anterior roots of the sacral nerves, as they form the *cauda equina* within the tube of the vertebræ. The tumour was of the form of an almond, but larger, and into it, the motor roots, both of the right and left side, were gathered, whilst the sensitive roots were free. The peculiar circumstances attending the case were communicated to me while the patient, who was in the public hospital of Edinburgh, was alive. The lower extremities were deprived of motion, whilst they retained sensibility; and symptoms of so much interest were noted and discussed by the physicians and pupils.

When a tumour on a nerve interrupts the communication between the brain and the extremity of the nerve, and the consequences are observed, they are conclusive as to the functions of that nerve, and afford a proof of them much superior to experiment. When a case of disease in the fifth nerve of the brain presents itself, the insensibility of the side of the tongue, of the side of the face and head, and of all the

cavities with the loss of power in the muscles of the jaw of that side, unequivocally confirm the deductions which I drew from the anatomy, that the fifth pair confers motion and sensation, in correspondence with its rising from the brain by two roots. In such a case, the trunk of the nerve, consisting of the united roots, is affected; and the privation of function is complete. In the present instance, the motion alone of the limbs was lost, by the destruction of the anterior roots of the nerves; whilst the sensibility remained, owing to the posterior roots being unaffected.

I am unwilling to enter on so great a subject as the influence of the cerebellum, and of that posterior column of the spinal marrow which descends from it. Important as these parts must be in the oeconomy, there are no facts to countenance the belief, that they are directly connected with the functions of motion and sensibility. Indeed the posterior column of the spinal marrow has been found softened to a degree, which we must suppose inconsistent with the continuance of its functions; and yet sensibility has been entire. But let not this fact militate against our conclusions. The column in the spinal marrow which gives rise to the sensitive roots, is posterior to that from which the motor roots arise; but is not the posterior portion of the spinal marrow. Some have imagined, from finding the posterior column of the spinal marrow softened, in cases where sensibility was entire during the life of the patient, that they had found an argument unfavourable to our general conclusions.

In consideration that the results of the experiments on the roots of the nerves of the spine, first made thirty years ago, have thus been confirmed by pathology, the Society will perhaps permit me to state how I was induced to commence these experiments. In thus adverting to my early investigations, I am only desirous of showing the principle which guided me in these pursuits.

Some of the physiologists, at home and abroad, who have treated of this subject, have appeared to consider the facts brought out by the experiments on the spinal nerves, as accidental results. Misconceiving the just application of experiments to this inquiry, they have made it a boast, that they proceeded to their experiments without preparation; and have gone so far as to represent the person who dissects living animals, indifferent to the results, and only curious to find something new, as the true philosopher! However this may be, my experiments on the spinal marrow and roots of the nerves were not undertaken till after long consideration and much minute dissection. Many of my pupils, now risen to eminence, may remember that at the time alluded to, my lectures on the nervous system extended beyond what was customary in the courses delivered in London: not trusting to preparations, minute dissections were made for each lecture; and to afford time for these, discussions on the physiology and pathology of the nervous system were thrown into the demonstration.

The first lecture on the distribution of the nerves, was upon presenting a display of the *first, second, third, fourth, fifth, and sixth* nerves. It appeared incumbent on me

to remark, that between the opinions taught in the schools, and the inferences to be deduced from the distribution of these nerves, there was no correspondence. Why do six nerves pass into the orbit? Why should two nerves descend into the nose? Why should three nerves penetrate the coats of the eye? Why should some of these nerves have ganglions on them and others none? If it be correct, that the brain is the *officina spirituum*, and gives out a common influence through the nerves, what is the meaning of this intricacy in the distribution of the nerves? I then held the following argument. Common occurrences, and the symptoms of disease, correspond with the anatomical facts, while they are adverse to the received opinions.

1. A catarrhal inflammation of the membrane of the nose is attended with the loss of the sense of smelling, and the increase of the sensibility to common irritation. Does not this imply a difference in the functions of the first and of the fifth nerve? and that their offices are not transferable?

2. In performing the operation of couching the cataract, as the needle touches the surface of the eye, it pricks it, and the patient feels a pain similar to what he would do were the skin pricked; but as the needle passes through the retina, he has a flash of fire. Does not this imply a difference of sensibility from the same injury, or the same impulse? Do we not perceive that there is a nerve of vision, and a nerve appropriated to the external surface?

3. When we receive a blow on the head, does not the same vibration affect the nerves of sense differently? In the ear, it produces sound as of the ringing of bells; in the eye, corruscations of light.

4. But here is the third nerve passing into the eye; is it also for sensation, or is there a motion of the iris to be established in relation to the sensorial impressions?

5. Shall we admit the interpretation, that the brain is the common sensorium, and that the peculiar office and sensibility of the external organ of sense result from the organization of the extremity of the nerve? On the contrary, it is capable of proof, that the trunk of a nerve, even of sense, receives and conveys an impulse which gives rise to the ideas belonging to that sense and to no other. The agony which accompanies the extirpation of the eye, forbids us to expect an account of the sensation experienced when the optic nerve is cut across. But we have other proofs. When the pudic nerve is exposed, the sensation is that which is appropriate to the glans.

The subject was followed up in the succeeding lecture; which, in order, was a demonstration of the nerves of the tongue—where three nerves are given to one organ.

Such, then, were the suggestions from anatomy and common experience, which led me to the conclusion, that nerves have appropriate properties; and that these properties are derived from the roots of the nerves, that is, their origins in the brain. To verify this view, I was first led to make experiments on the brain. These proved futile; and I then thought of determining the matter by experiments on the spinal marrow, and the roots of the spinal nerves.

The Society must perceive, that when it was demonstrated that the anterior and posterior roots differed in function, the whole investigation became anatomical. Tracing the column of the spinal marrow which gives rise to the anterior roots, upwards, we meet with the ninth, sixth, and third, arising from the same tract; and as these are distributed to muscles exclusively, we must infer that they are motor nerves; thus confirming the deductions from the experiments, that the whole anterior column gives off only nerves of motion.

It must likewise be obvious how these investigations into the functions of the spinal nerves, their roots and columns, carried me back to the original field of inquiry, the cerebral nerves; and this conducted me to the observation, that the fifth pair of the brain is analogous, in the structure of its roots, and its functions, to the spinal nerves.

The next subject to which I request the indulgent attention of the Society, regards those nerves, which in a paper delivered in 1821, I called

The Respiratory System of Nerves.

I foresaw that my views on this subject would prove embarrassing to physiologists. But the length of time that has elapsed, and the ingenuity of many men who have engaged in the investigation, have made it ripe for further inquiry.

In the paper alluded to, certain nerves, very distinct from the thirty spinal nerves and fifth pair, which from their uniformity of origin and course I called regular nerves, were pointed out. These nerves also bore distinct features from the nerves of the encephalon. They were the *portio dura* of the seventh nerve, the glossopharyngeal nerve, and the spinal accessory nerve; to which I added the diaphragmatic, and external respiratory nerve.

As these nerves are peculiar in their origins, so are they in their course and distribution. On the outside of the *corpus olivare*, and anterior to the *processus ad cerebellum*, when the pia mater is torn away, a tract, marked by the size of the holes from which the nourishing vessels have been withdrawn, and continued downwards behind the *ligamenta denticulata*, is perceived; from the upper part of this column these nerves arise conspicuously, and from this they diverge as from a centre. They differ in length, and perhaps in importance; but they go to every part, throughout the extended frame, associated in the act of respiration, or in the many lesser actions in which the organs of respiration participate.

Another circumstance was pointed out as marking their peculiarity. When sense and volition are lost, and the individual is dying, these nerves retain their power, and are the last to yield to the influence of death.

In marking the difference in these nerves from the regular spinal nerves and fifth pair, we may add to their peculiar mode of origin, the distinction in the columns from which they arise. The peculiarity of the columns which give origin to the regular nerves is their decussations: but such decussations are not found in the columns which give off the respiratory nerves.

Let us be distinct. There are two anterior or motor columns in the spinal marrow; and two, more posteriorly situated, sensitive columns. These resemble each other in this, that they respectively interchange filaments, the anterior columns with each other, and the posterior columns with each other.

No other columns of the spinal marrow make this interchange; and the respiratory columns are far apart.

It is not unnatural to conclude that such interchange is necessary to the infinite varieties in the associated actions of the frame, where sensation and voluntary motion are in operation; whilst the uniformity of the respiratory act requires no such provision. At all events, the respiratory nerves arise from columns which do not decussate, a circumstance which distinguishes the systems.

It was an early object with me, to make out the connexion between the roots of the diaphragmatic nerve and of the spinal accessory nerve. I conceived that as these nerves were closely united in office, the latter elevating the shoulders, so as to assist in the due expansion of the chest, while the former excites the diaphragm*—for the expansion of the chest is necessary to the full action of the diaphragm—they might have the same origin. But independently of anatomical investigation, and waiting for those occurrences in practice which are perhaps better than experiment, symptoms seem to confirm the correctness of this view.

In the case already alluded to, of disease in the bodies of the cervical vertebrae, and which I have selected from among others, merely because at the time of writing it is a subject of daily inspection, the common muscular motions of the neck and arms are entirely suspended, whilst the breathing is not, and never has been affected. The arms hang like empty sleeves, the head falls forward, if not supported with the hand or by an instrument, the muscles are wasted, and the neck thin; yet in breathing, the mastoid muscle and the trapezius muscle swell and become as firm as a piece of board.

Anatomical investigation shows the roots of the spinal accessory nerve arising far apart from the muscular roots of the nerves of the arms: indeed they are more nearly allied to the roots of sensation than of motion; and in the instance above, we find common muscular actions cut off, and those of respiration perfect. We see the sensibility in the whole extent of the respiratory passages, and the influence of the will retained, through the respiratory nerves. The same phenomena are presented in the common case of hemiplegia.

Such facts countenance the view which was presented to the Society, where a peculiar office was ascribed to these nerves, and a distinct name given to them.

But there remain some questions of great difficulty and much interest. And I am now happy in taking the assistance of the experiments made by various ingenious gentlemen.

* Some have supposed that the diaphragm expands the chest laterally; an effect which I cannot conceive possible.

When the dissected body exhibits to us this extensive class of respiratory nerves, traceable from a centre to all the organs of respiration, a question arises, by what means do the sensibilities of the pharynx, larynx, lungs, stomach, bring these respiratory nerves and muscles into action? Is the system which we have been considering complete in itself? Are these respiratory nerves both sensitive and muscular? Are the necessary sensations propagated along sensitive nerves bound up with the muscular respiratory nerves, or do they owe their sensibility to the numerous connexions with the regular nerves formed in their course?

That a regular nerve may animate the whole class of respiratory nerves is demonstrated in the office of the fifth, in the Schneiderian membrane. The sensibility of the cavities of the nose bestowed by the branches of the fifth nerve, excites the act of sneezing.

But, on the other hand, if we place confidence in the experiments of VALENTIN on the roots of the *Vagus*, it is purely the central sensitive nerve of the respiratory system; for having exposed its roots, and taken them off from the side of the *medulla oblongata*, and at the same time having separated them from the roots of the glosso-pharyngeal nerve and spinal accessory nerve, he irritates these roots of the *vagus*, and finds no consequent action in the pharynx, stomach, or respiratory muscles: no motion is produced.

But again, taking the trunk of this nerve, where it lies in the neck, all the connexions of the nerve being entire, the irritation of it produces muscular actions, and the act of respiration is imitated.

There is no doubt that the *nervus vagus* is a sensitive nerve. When I have examined the abdomen of a man completely paralytic from disease, or from fracture of the vertebræ high up, the patient, though outwardly insensible below the neck, has felt when I pressed the stomach.

Again, with respect to the glosso-pharyngeal nerve, the experiments of Dr. REID go to prove it a sensitive nerve. It is impossible to cavil at these experiments. They were often repeated, and with a perfect understanding of the subject. He first finds that pinching the nerve gives pain. He then divides the nerve, and irritates the divided portion next the brain, by which muscular movements are produced in the throat.

I am well aware that, dissecting deep among nerves, the experimenter is subject to be mistaken; and in surgical operations on the human body, the exposed trunks of nerves give little pain, compared with the fine sensibility of their extremities. We find experiments by different hands giving different results, and the same experiments differing on one day from another, performed by the same person.

But the force of evidence is all in favour of the *nervus vagus* and the *glosso-pharyngeal* nerve being sensitive. And Dr. REID's experiments give a perfect example of what I have called the *Nervous Circle**; the sensibility or nervous influence flow-

* Phil. Trans. 1826. p. 163.

ing towards the origin of the nerve, to be returned by parallel nerves upon the muscles: for the uniformity of nature's laws is maintained in both the great systems, the regular, and the respiratory.

Experiments countenance another early conclusion. Of the three conspicuous nerves of this system which have been associated under the name of the eighth pair of nerves, the spinal accessory nerve is proved to be the essential muscular nerve. The experiments of Professor MÜLLER, Drs. REID and VALENTIN, exhibit this nerve as purely muscular.

I drew this conclusion when I presented to the Society the plan of the respiratory nerves and muscles. I suggested that the roots of the spinal accessory nerve and of the diaphragmatic nerve arose from the same portion of nervous matter: and that whilst the one went directly, and by the shortest way to the diaphragm, the other proceeded upwards, entered the head, and came down in association with the other nerves, in order, by these communications, to unite the motions of the air-tubes with the play of the chest in respiration, and that the whole respiratory apparatus might consent in action. Often as I have set my young friends to determine the question by dissection, I have found them puzzling and giving up the pursuit. No doubt the dissection is difficult; and we must still rest satisfied with a process of reasoning. The influence of these nerves is necessary to each other. The muscles of the chest and the diaphragm continue in action when the motions of the arm and of the muscles of the neck are lost. These nerves and their respective muscles continue in office when both sense and motion are gone.

In making two distinct systems of the nerves arising from the spinal column, it was never my intention that it should be believed that they were cut off from the sensorium. The connexion of the brain with the spinal marrow is a distinct subject of inquiry.

We know that concatenated motions can be excited in the body where there is no brain. We know that the action of respiration will continue when the brain is taken away; so far, then, it is obvious that the relations of the frame, whether for the purpose of locomotion and action, or of breathing, are perfect, independently of cerebrum and cerebellum. The question remains, what is the nature of that relation, or of that influence, maintained by the brain over the nervous system of the body? However that connexion may hereafter be found to be established, it will not invalidate the conclusions as to the unity of office of the nerves employed in respiration, and in the actions where the respiratory apparatus is brought into play.

Before concluding this subject, it is pertinent to notice, that writers have been led to attribute the entire action of respiration to the sensation in the lungs. To a certain degree this is undoubtedly true. When I formerly stated, that upon dividing the *par vagum* (and with it the sympathetic nerve), and cutting through the spinal marrow, the act of respiration continued, I established the fact that there was a source of motion in the respiratory organs independently of any sensation in the lungs. I

may be permitted to doubt, if in common breathing there is any sensation; we are certainly not conscious of it. It cannot at least be anything like the exercise of sensibility of which we are conscious, and which is wearied and exhausted by repetition. There is then, we must apprehend, another source of the regulated drawing of breath, which excites the respiratory muscles not to occasional and sudden actions, but to the constant combined action of opening the passages to the air. Even in the decapitated head, this influence will cause the muscles of the nostrils to be drawn repeatedly, as in natural breathing*.

Of the Supply of Blood to the Nerves of the Respiratory System.

We have seen that the lateral part of the *medulla oblongata* and cervical part of the spinal marrow are more necessary to life than the brain itself; that as on this part and the nerves thence arising, the actions of respiration depend, the phenomena of life depend more directly upon them than on any part of the animal body.

It being at the same time perfectly well understood, that no quality of brain or nerve, or vital property in any part, can exist without a supply of arterial blood, it becomes an object of interest to know how nature has provided for a bountiful arterial circulation to these important organs.

Our books, in treating of the circulation in the brain, state that the supply of blood to it is very much greater than to any other part of equal weight. This is correct, and would of itself mark the importance of the organ. But in proceeding to show how this is accomplished, they state, that four great arteries ascend to the brain, and that of these the vertebral arteries, for greater security against the supply of blood being dangerously diminished, ascend through the foramina in the cervical vertebræ. We object to this last conclusion.

It is not to secure the free circulation through the brain that the vertebral arteries take this tortuous and concealed course. It is for the supply of arterial blood to these vital nerves, and to that part of the spinal marrow which gives origin to them.

This idea suggested itself to me on observing, in a subject minutely injected, with what a copious supply of tortuous arteries these nerves and the side of the *medulla oblongata* were surrounded. When these arteries, branches of the vertebral artery, and their accompanying veins were removed, we saw the foramina by which they enter into the respiratory column conspicuous beyond what is seen in other parts.

This opinion was pointed out in a former paper†; but the subject acquires a higher interest from the observations of Sir ASTLEY COOPER. He found that, on compressing the vertebral arteries at the lower part of the neck, where they are about to enter

* The head gasps in successive actions after decapitation.—LEGALLOIS. Breathing continued after the pithing of the animal in the cervical region, and after the brain and cerebellum had been removed and the vagi divided in the neck.—Dr. REID. "I have seen the respiratory muscles twice called into simultaneous movement after all the thoracic viscera had been rapidly removed," &c.—Dr. REID.

† See the Nervous System, p. 119.

the canal of the bone, the animal ceased to breathe. It did not die like an animal suffocated by compression of the windpipe, but there came a gradual subsidence of the motion of respiration, evincing that the source of activity and of sensibility in the centre of the respiratory system was withdrawn.

Practically considered, this is a subject of interest. Are we not daily seeking for the cause of sudden death in organs, the condition of which cannot explain the phenomena; for example, the heart and brain? The pathologist is satisfied when he finds the heart in a slight degree removed from a condition of health; and yet he must be aware that when wounded or deeply diseased, death is protracted: there is the agitation of dying, the labour of these organs of respiration. It is only in violent injury, which shall affect the centre of the respiratory system, that there is no act of dying, but a sudden cessation of all action. The bruiser, on receiving a blow on the throat, or a blow on the stomach unexpectedly, is killed, as by the *coup-de-grace* given to the malefactor broken on the wheel. He dies instantly without a sigh, and without a motion of the features indicative of agony.

Are not these instances of injury propagated to the centre of the nerves of this system, on which the vital action of respiration and expression depend? The cause is equal to the effect; while death from organic lesion in the thorax, is attended with symptoms, with suffering, more or less prolonged, *with the act of dying*.

XIV. *Researches on the Tides.—Twelfth Series. On the Laws of the Rise and Fall of the Sea's Surface during each Tide.* By the Rev. W. WHEWELL, B.D. F.R.S., Fellow of Trinity College, Cambridge.

Received June 13,—Read June 18, 1840.

THE subject of the present communication is different in its nature from those of previous memoirs on the tides presented by me, and printed by the Society; since it refers, not to comparison of the times and heights of different tides, but to the rate of the rise and fall of the surface of the water in successive stages of the same tide. This inquiry has often been prosecuted at particular places by naval observers, and is of very material importance to navigation. For even supposing the time and height of high water to be known, it is still often requisite, for nautical purposes, to know the height of the water at a given interval before or after the moment of high water. And this inquiry may be the more useful, inasmuch as the laws of rise and fall of the surface are nearly the same at all places; the differences being, for the most part, of such a kind as can be ascertained and allowed for without much difficulty. Hence these laws, once stated, will be applicable on every coast; and the knowledge of them may supersede those laborious trains of observation which have often been instituted in order to ascertain the laws at particular places.

The materials of the present investigation (which is principally founded upon observation) are the following:—Five months' tide observations made at Plymouth, in which, besides the time and height of high and low water, the time of the surface passing two lines above the level of mean water was carefully observed; these latter observations being made, at my request, by direction of the Lords Commissioners of the Admiralty:—Three months' observations (taken out of a larger series) made at Liverpool, under the direction of Capt. DENHAM, R.N., in which the height of the surface was noted every half hour:—and twelve months' observations made at Bristol by Mr. BUNT, by means of his tide-gauge. The latter observations were reduced by Mr. BUNT himself; the others were discussed under my direction by Mr. DESSIOU and Mr. Ross, of the Hydrographer's Office, with their usual care and skill.

Whatever be the exact law of the rise and fall of the tide, if the rise and fall be nearly symmetrical (which it usually is), the height of the surface of the water at a given place will increase nearly as the sine, while the time increases as the arc. Hence, if we were to make the time the *abscissa* and the height the *ordinate*, we should obtain (for one tide) the *figure of sines* for our curve. Or, to put the matter otherwise: if we suppose a point to move uniformly through the circumference of a circle in a tidal

half-day, the height of this point above a horizontal line will represent the height of the surface of the water, supposing the velocity and the radius to be duly adjusted.

But the radius depends upon the total rise of the surface, and the velocity depends on the length of a tidal day, and both these quantities are different at different periods of a lunation. Hence our line of sines will, even theoretically, require some modification.

Let the height of the surface above a given zero line be

$$y = k + h \cos \frac{2\pi t}{\tau},$$

where τ is the length of the tidal half-day, and t the time from high water; $2h$ the rise from low water to high water.

The quantity τ will (according to theory) differ at different periods of the semilunation. The law of its change is determined as follows:

Let ϕ be the R.A. of the moon *minus* a certain constant, and θ the time at which the high water (or low water) follows the moon's transit, *minus* a certain other constant; c the ratio of the solar to the lunar tide. Then by the equilibrium theory we have

$$\tan 2\theta = -\frac{c \sin 2\phi}{1 + c \cos 2\phi}.$$

Also if ϕ' , θ' , be the values of ϕ , θ , at the next tide,

$$\tan 2\theta' = -\frac{c \sin 2\phi'}{1 + c \cos 2\phi'}.$$

$$\text{Hence } \tan (2\theta' - 2\theta) = -\frac{c(\sin 2\phi' - \sin 2\phi) + c^2 \sin 2(\phi' - \phi)}{1 + c(\cos 2\phi' + \cos 2\phi) + c^2}$$

$$= -\frac{c \cos (\phi' + \phi) + c^2 \cos (\phi' - \phi)}{1 + 2c \cos (\phi' + \phi) \cos (\phi' - \phi) + c^2} 2 \sin (\phi' - \phi).$$

But the arcs $2\theta' - 2\theta$ and $\phi' - \phi$ are small, and very nearly as their tangents and sines. Also $\cos (\phi' - \phi) = 1$, nearly, and $\cos (\phi' + \phi) = \cos 2\phi$, nearly.

$$\text{Hence } \theta' - \theta = -(\phi' - \phi) \frac{c \cos 2\phi + c^2}{1 + 2c \cos 2\phi + c^2},$$

$$\text{whence } \theta' - \theta + \phi' - \phi = \frac{1 + c \cos 2\phi}{1 + 2c \cos 2\phi + c^2} (\phi' - \phi).$$

Now the former tide happens $\phi + \theta$ after the sun's transit, and the latter tide $\phi' + \theta'$ after the sun's next transit; therefore the length of the tidal half-day is $12^h + \theta' + \phi' - \theta - \phi$. Also $\phi' - \phi$ is constant, being always very nearly 24 minutes. Hence the tidal half-day will be least and greatest when the above fraction is so; that is, when 2ϕ is 0 and π . The tidal half-day is therefore least at spring tides, when it is

$$12^h + \frac{\phi' - \phi}{1 + c};$$

and greatest at neap tides, when it is

$$12^h + \frac{\phi' - \phi}{1 - c}.$$

If we take $\phi' - \phi$ to be 24 minutes, and c to be $\frac{9}{5}$, which is the value which agrees best with the times at Plymouth, these tidal half-days are respectively $12^h 17^m$ and $12^h 40^m$. At any other time

$$\tau = 12^h + 24^m \frac{1 + c \cos 2\phi}{1 + 2c \cos 2\phi + c^2} = 12^h \left\{ 1 + \frac{1}{30} \cdot \frac{1 + c \cos 2\phi}{1 + 2c \cos 2\phi + c^2} \right\}.$$

The height, $2h$, of the total tide varies with the period of the lunation. If $2H$ be the total lunar tide,

$$\text{at springs } h = H(1 + c').$$

$$\text{at neaps } h = H(1 - c').$$

$$\text{at any time } h = H\sqrt{1 + 2c' \cos 2\phi + c'^2};$$

but c' has no longer at all places the same value as c before. The Liverpool tides give $\frac{2}{3}$ as the value of c' : but in order to satisfy the Plymouth observations of height, c' must be about $\frac{1}{4}$.

Since the curve of rise and fall at spring tides has its amplitude the smallest and its ordinate the largest, it will intersect all the others. The points of intersection will be a little above mean water.

We have now to inquire whether these features appear in the empirical laws of the tides, as collected from discussion of the observations already spoken of: namely, whether the curve of rise and fall is the figure of sines, and whether its maximum ordinate (h) and its amplitude (τ) follow laws resembling those given by the theory. If this is the case, the intersections of the curves will also agree with the theory.

(1.) The empirical curve of rise and fall agrees very nearly with the figure of sines at all the three places here considered. The figure was determined differently at the different places. At Liverpool, where the height of the water was observed every half hour, the total curve was given empirically, and is exhibited in Plate X. fig. 1., the curves being thrown into two groups (according to hours of moon's transit) to avoid confusion. At Plymouth, the time and height of high water were observed, and also the time of passing two horizontal lines (M and N) situated near mean water (at nine feet ten inches and ten feet ten inches respectively, above the zero of the scale). By this means five points were given in each curve, (the observations being arranged according to the hour of transit), and the curves were drawn by the eye through these points, as may be seen in fig. 2.

At Bristol, the tide-gauge did not allow the rise and fall to be observed more than half way down from high water to mean water; but there is no doubt that in its general law of variation, the curve approached nearly to the figure of sines.

(2.) But in all these cases, more or less, there is a deviation of the empirical from the theoretical form, which deserves notice. Instead of being a symmetrical curve,

the rise and the fall taking place at the same rate, the empirical curve of rise and fall is unsymmetrical, the fall being more rapid than the rise in general, though sometimes the reverse occurs. By this means the *summit* of the curve of rise and fall is *displaced*, and is posited to the right or left of the position given by *bisecting the interval* of the times at which the surface, in rising and in falling, passes some lower line (as the line of mean water). This *displacement of the summit* I have taken at Liverpool for two lines (M and N) at the heights of fifteen feet and seventeen feet above the zero; at Plymouth for two lines (M and N) which, as above stated, are at nine feet ten inches and ten feet ten inches above the zero. In these cases the lines M and N are very near *mean water*. At Bristol, as I have said, the lower observed height was half way from mean water to high water.

The displacement of the summit being arranged according to the hour of moon's transit, there is no obvious agreement in the form of the result for different places. Fig. 3. and 4. give the curves which express these results for Plymouth and Liverpool; Bristol is not readily comparable with these, from the nature of the observations.

(3.) The variations in the length of the *tidal half-day* (from low water to low water) were also examined. It appeared that at Liverpool and at Plymouth the variations in this element followed nearly the law indicated by the theory; which, indeed, may be considered as having been previously sufficiently proved by the near accordance of the observed with the theoretical times of high and low water; an accordance which had already been established by the discussion of the observations at Liverpool, London, and other places.

(4.) The same may be said of the variations in the height of high and low water during a semilunation. It had already been repeatedly shown, that (if we assume a proper value of *c*) these, as observed, agree with great accuracy with the theory, at every place yet examined.

(5.) Hence, as I have said, the intersections of the curves of rise and fall belonging to different hours follow, in the curves given by observations, nearly the theoretical law. Thus these intersections all take place nearly at mean water; but occur a little higher and nearer high water than the height and time of mean water.

(6.) But yet the want of exact symmetry in the empirical curves occasions some peculiar features in the intersections of these curves. Thus, at least for many of the hours of transit, the intersections of the curves of rise and fall are higher and nearer the time of high water in descending than in ascending. This may be seen in the Liverpool curves, in which many of the ascending intersections fall very near the line M, while the corresponding descending intersections fall near the line N.

(7.) Since the time of ascending is greater, and the height ascended less, at neaps than at springs, it is plain that the velocity of ascent must be greater, and the time of ascending a given space less, at springs than at neaps. The same is the case of descent. And hence the times of ascending from M to N vary, and this variation appears eminently in the rate of the surfaces ascending or descending about mean

water. I have compared the times of ascending a given space (from M to N) both at Liverpool and at Plymouth, but I have not thought it necessary to give the diagram which exhibits the result.

(8.) Near mean water the surface is rising or falling with the greatest velocity. Hence the observation of the time at which the surface passes the line M or N is far more precise than the observation of high and low water. The observations at Plymouth were made to seconds; and the hypothetical time of high water, obtained by bisecting the interval from M rising to M falling, agreed with the time obtained by bisecting the interval between N rising and N falling, generally within a minute or two, and often within a few seconds.

(9.) Since this is the case, it might be made a question, whether it would not be better to observe the time of the surface passing M, or N, or both, than to observe the time of high water and low water. (Of course it must be understood, that it would still be requisite to observe the *height* of high water and low water, but this is very easily done, either by the eye, or by self-registering machinery.) There are some circumstances which appear to confirm the conjecture that this would be an improvement in tide observations: for instance, the *diurnal inequality* of the times of high water at Plymouth is much more distinctly seen in the bisected times than in the observed times; but on examining the general run of the observations, it does not appear that the bisected times are more regular than the observed times.

Since the exactness with which it is possible to determine the bisected time of high water has not previously been practically shown, I shall give, at the end of this memoir, the comparison of the bisected times obtained from the lines M and N at Plymouth, with each other, and with the observed times of high water.

(10.) As we have already seen, the displacement of the summit of the curves of rise and fall, that is, the time by which the observed time of high water differs from the bisected time, appears to follow different laws at different places, and therefore probably depends upon local circumstances. In general, in the cases hitherto examined, the observed time is later than the bisected time; that is, the surface descends more rapidly than it rose. But both at Liverpool and Plymouth this difference vanishes very nearly at about seven hours' transit. Thus at neap tides the curve of rise and fall is nearly symmetrical.

(11.) The laws which we have investigated have been referred to the hours of the moon's transit, these hours being reckoned from 1 to 12; but at Plymouth, if we refer the observations to hours of moon's transit from 1 to 24, thus distinguishing superior from inferior transits, we find a great difference in the effects belonging to corresponding transits, as 6^h and 18^h, 7^h and 19^h, and the like. This difference apparently arises from a diurnal inequality, and would disappear when the moon's nodes came into another position.

London, June 12, 1840.

P.S. I will add to the above memoir two tables, giving the height of the surface of the sea at any time, as affected by the tide at Plymouth and at Liverpool. In constructing these tables I have supposed the rise and fall of the surface to follow the law of the sine of the time from mean water, as already explained. For although there exists in many places a *displacement of the summit* of the curve of rise and fall, this displacement is small, and would not much affect the height at any time. Whether it arise from the combination of the solar with the lunar tide-wave, or of the diurnal with the semidiurnal wave, or from the form of the channel and local circumstances, it may be disregarded or postponed in a statement like the present.

The height is given in these tables according to hours *before* and *after* high water, the curve being supposed symmetrical, as we have said. The *unit* of height (expressed in the table by 1000) is the height of the high water at spring tides above the *mean water*, or half the total rise of the surface at spring tides. The table must be adapted to any particular place by multiplying each tabular number by this quantity (the height of spring tide high water above mean water) for the place (cutting off three decimal places).

The highest spring tides and the lowest neap tides take place at different intervals after the moon's syzygies and quadratures at different places, the interval varying from a few hours to a few days. In like manner the tides *corresponding* to the moon's *octants* (when her transit takes place three hours after the sun's) follow the time of the octants at different intervals at different places; but they may be very intelligibly designated as *octant tides*, which term is employed in the tables.

In the table for Plymouth, the spring tide is to the neap tide as 5 to 3; which supposes the solar tide to be *one fourth* of the lunar tide. In the table for Liverpool, the spring tide is to the neap tide as 7 to 3; which supposes the solar tide to be *two fifths* of the lunar. These are the proportions given by observation at those places.

I will add an *Example* of the use of the following tables. Let it be proposed to *find the height of the surface at Plymouth $1\frac{1}{2}$ hour before high water at octant tides*. The range of spring tides at Plymouth is sixteen feet; hence the unit of heights is eight feet; and at $1\frac{1}{2}$ hour before high water the tabular number (by interpolation) is .515. Hence the height above mean water is 4.12 feet, or four feet one inch; and since mean water is at nine feet ten inches on the scale, the height of the surface on the scale is thirteen feet eleven inches at the time proposed.

Tables of the Elevation or Depression of the Surface of the Sea above or below Mean Water at all hours of the Tide.

FOR PLYMOUTH.

Before or after High Water.	Spring Tides.	Octant Tides.	Neap Tides.
Above mean water. $\left\{ \begin{array}{l} h \quad m \\ 0 \quad 0 \\ 0 \quad 30 \\ 1 \quad 0 \\ 1 \quad 30 \\ 2 \quad 0 \\ 2 \quad 30 \\ 3 \quad 0 \end{array} \right.$	$\left\{ \begin{array}{l} 1000 \\ 979 \\ 872 \\ 720 \\ 522 \\ 289 \\ 041 \end{array} \right.$	$\left\{ \begin{array}{l} 825 \\ 797 \\ 721 \\ 599 \\ 432 \\ 245 \\ 038 \end{array} \right.$	$\left\{ \begin{array}{l} 600 \\ 584 \\ 530 \\ 441 \\ 330 \\ 194 \\ 047 \end{array} \right.$
Below. $\left\{ \begin{array}{l} 3 \quad 30 \\ 4 \quad 0 \\ 4 \quad 30 \\ 5 \quad 0 \\ 5 \quad 30 \\ 6 \quad 0 \end{array} \right.$	$\left\{ \begin{array}{l} 217 \\ 462 \\ 665 \\ 834 \\ 945 \\ 996 \end{array} \right.$	$\left\{ \begin{array}{l} 172 \\ 367 \\ 541 \\ 679 \\ 772 \\ 818 \end{array} \right.$	$\left\{ \begin{array}{l} 100 \\ 243 \\ 371 \\ 470 \\ 550 \\ 592 \end{array} \right.$
Low water..	1000	825	600
Time	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 8 \end{array} \right.$	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 11 \end{array} \right.$	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 20 \end{array} \right.$

At 2^h 52^m before and after high water, the surface, both at neaps and springs, is 57 of the parts above mean water, that is $\frac{57}{35}$ th of the tidal unit.

FOR LIVERPOOL.

Before or after High Water.	Spring Tides.	Octant Tides.	Neap Tides.
Above mean water. $\left\{ \begin{array}{l} h \quad m \\ 0 \quad 0 \\ 0 \quad 30 \\ 1 \quad 0 \\ 1 \quad 30 \\ 2 \quad 0 \\ 2 \quad 30 \\ 3 \quad 0 \end{array} \right.$	$\left\{ \begin{array}{l} 1000 \\ 979 \\ 872 \\ 720 \\ 522 \\ 289 \\ 041 \end{array} \right.$	$\left\{ \begin{array}{l} 775 \\ 748 \\ 677 \\ 562 \\ 405 \\ 230 \\ 635 \end{array} \right.$	$\left\{ \begin{array}{l} 429 \\ 417 \\ 379 \\ 315 \\ 236 \\ 139 \\ 033 \end{array} \right.$
Below. $\left\{ \begin{array}{l} 3 \quad 30 \\ 4 \quad 0 \\ 4 \quad 30 \\ 5 \quad 0 \\ 5 \quad 30 \\ 6 \quad 0 \end{array} \right.$	$\left\{ \begin{array}{l} 217 \\ 462 \\ 665 \\ 834 \\ 945 \\ 996 \end{array} \right.$	$\left\{ \begin{array}{l} 161 \\ 344 \\ 508 \\ 637 \\ 725 \\ 768 \end{array} \right.$	$\left\{ \begin{array}{l} 071 \\ 174 \\ 265 \\ 336 \\ 393 \\ 423 \end{array} \right.$
Low water..	1000	775	429
Time	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 9 \end{array} \right.$	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 11 \end{array} \right.$	$\left\{ \begin{array}{l} h \quad m \\ 6 \quad 19 \end{array} \right.$

Observations at Plymouth of the time when the Surface passes lines M and N; and the calculated Time of High Water, hence obtained, compared with the Observed Time.

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1839. December 1	h m s	h m s	h m s	h m s	h m s
1	5 34 23		5 2 20		
	10 7 45	1 59 46	10 31 26	1 59 0	1 45 0
	5 51 47		5 26 34		
	10 47 25	2 36 40	11 10 54	2 36 15	2 13 0
2	6 23 55		6 1 36		
	10 47 57	2 44 13	11 18 50	2 47 20	2 41 0
	6 40 30		6 15 51		
	11 30 3	3 16 36	11 51 13	3 15 58	3 2 0
3	7 3 10		6 40 42		
	11 49 49	3 33 54	0 9 38	3 33 39	3 28 0
	7 17 58		6 57 40		
4	0 16 10	4 0 6	0 35 21	3 58 46	3 50 0
	7 44 3		7 22 10	4 12 0	4 9 0
	0 31 39	4 12 50	0 50 29		
	7 54 0		7 32 30	4 33 41	4 27 0
5	0 55 5	4 33 30	1 16 10		
	8 11 54	4 52 24	7 51 13	4 51 6	4 45 0
	1 23 16		1 41 37		
6	8 21 31	5 12 20	8 0 34	5 14 53	5 4 0
	1 34 15		1 58 20		
	8 50 24	5 30 7	8 31 27	5 28 46	5 25 0
	1 51 24		2 8 47		
7	9 8 50	5 50 6	8 48 45	5 47 47	5 39 0
	2 5 50		2 17 54		
	9 34 22	6 2 18	9 17 39	6 0 52	6 0 0
	2 23 6		2 40 24		
8	9 41 30	6 20 50	9 21 20	6 21 11	6 11 0
	2 36 24		2 54 53		
	10 5 15	6 38 56	9 47 50	6 37 35	6 32 0
	3 1 52		3 19 15		
9	10 16 0	6 53 29	9 55 55	6 51 22	6 50 0
	3 9 30		3 24 24		
	10 37 28	7 14 11	10 18 19	7 11 22	7 7 0
	3 31 57		3 49 27		
10	10 56 25	7 24 58	10 33 14	7 27 27	7 27 0
	3 25 32		3 51 26		
	11 24 23	7 48 36	11 3 28	7 47 15	7 44 0
	3 59 40		4 20 23		
11	11 37 22	8 6 30	11 14 6	8 6 14	8 1 0
	4 1 20		4 22 0		
	0 11 39	8 27 33	11 50 27		
12	4 24 45		4 45 20	8 25 18	8 18
	0 30 20	8 40 33	0 5 15	8 42 7	8 42 0
	4 14 10		4 38 50		
	1 6 56	9 15 50	0 45 24	9 16 22	9 6 0
13	5 8 10		5 32 35		
	1 23 30	9 36 35	1 0 10	9 36 6	9 30 0
	5 15 5		5 40 0		
	1 58 5	10 14 40	1 32 11	10 11 2	9 50 0
14	6 4 15		6 30 3		
	2 25 5	10 32 19	1 52 0	10 29 14	10 19 0
	6 16 9		6 41 20		
	2 48 28	11 25 40	2 18 7	11 25 20	10 47 0
15	7 27 9		7 55 25		
	3 24 10		2 55 14		

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1839. December 15	h m s 3 24 10 7 32 40 4 5 0	h m s 11 49 20	h m s 2 55 14 7 58 5 3 34 20	h m s 11 46 13	h m s 11 30 0
16	8 22 10 4 27 15 8 50 55 4 45 25	0 25 12 0 48 10	8 51 40 3 58 46 9 18 46 4 25 10	0 25 10 0 51 58	11 59 0 0 39 0
17	9 50 45 5 27 15 10 8 19 6 15 35	1 39 0 2 11 57	10 14 0 5 4 30 10 26 49 5 53 50	1 39 15 2 10 20	1 9 0 1 45 0
18	10 41 45 6 47 52 11 6 17 7 13 10 11 50 41	2 44 49 3 9 44	10 59 40 6 29 16 F1 24 22 6 54 50	2 44 28 3 9 36	2 20 0 2 54 0
19	7 37 59 0 17 41 8 12 46	3 44 20 4 15 14	0 7 10 7 20 20 0 35 38 7 48 15	3 43 45 4 11 57	2 26 0 3 36 0
20	0 41 54 8 42 48 1 11 41 9 5 30	4 42 21 5 8 36	0 53 52 8 27 18 1 26 22 8 50 40	4 40 35 5 8 31	4 21 0 4 48 0
21	1 25 10 9 27 44 2 8 12 9 56 8	5 26 27 6 2 10	1 49 15 9 14 19 2 22 3 9 42 19	5 31 47 6 2 11	5 16 0 5 40 0
22	2 29 15 10 23 40 2 55 23 10 53 41	6 26 28 6 54 2	2 42 30 10 11 25 3 10 35 10 36 4	6 26 57 6 53 20	6 17 0 6 33 0
23	3 13 40 11 8 41 3 43 10 11 46 30	7 11 11 7 44 50	3 25 20 10 57 28 3 57 45 11 28 50	7 11 24 7 43 17	7 2 0 7 25 0
24	3 44 47 0 2 36 4 10 10 0 17 4	7 53 42 8 13 37	3 56 17 11 48 16 4 33 5 0 2 17	7 52 17 8 17 41	7 48 0 8 5 0
25	4 34 40 0 34 25 5 15 45 0 53 16	8 34 33 9 4 31	4 56 30 0 16 8 5 32 5 0 32 30	8 36 19 9 2 18	8 26 0 8 45 0
26	5 16 52 1 34 21 5 34 22 1 57 40	9 25 37 9 46 1	5 34 2 1 13 2 5 52 7 1 28 15	9 23 32 9 40 11	9 11 0 9 30 0
27	5 49 43 2 14 2 6 24 29 2 40 46	10 1 53 10 32 38	6 9 23 1 49 28 6 48 38 2 10 20	9 59 26 10 29 29	9 53 0 10 12 0
28	6 35 22 2 57 42 7 25 20 3 25 20	10 46 32 11 25 20	6 59 15 2 25 20 7 54 30 2 50 50	10 42 18 11 22 40	10 34 0 10 52 0
29					

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1839.	h m s	h m s	h m s	h m s	h m s
December 29	3 25 20		2 50 50		
	7 27 30	11 42 51	7 59 30	11 40 38	11 25 0
	3 58 12		3 21 45		
30	8 15 30	0 23 10	8 49 15	0 21 30	11 47 0
	4 30 50		3 53 45		
	8 32 16	0 41 39	9 5 10	0 40 57	0 14 0
	4 51 2		4 16 44		
31	9 32 34	1 5 4	10 4 58	1 2 59	0 48 0
	4 57 33		4 1 20		
	9 49 43	1 51 27	10 21 2	1 53 26	1 21 0
	5 53 30		5 25 45		
1840.	10 31 40	2 37 25	11 9 51	2 39 6	2 4 0
January 1	6 43 10		6 8 20		
	10 52 4	3 0 22	11 19 8	3 2 11	2 33 3
	7 8 40		6 45 15		
	11 10 20	3 21 33	11 35 40	3 22 59	3 3 0
2	7 32 45		7 10 18		3 28 0
	11 57 51	3 43 58	0 21 39	3 43 25	3 58 0
3	7 30 5		7 5 10		
	0 34 45	4 16 38	0 55 8	4 14 37	4 27 0
	7 58 30		7 34 6		
	0 57 22	4 36 33	1 17 2	4 35 52	4 51 0
4	8 15 43		7 54 41		
	1 3 52	4 54 24	1 22 21	4 53 51	5 5 0
	8 44 56		8 25 21		
	1 27 41	5 15 28	1 46 11	5 13 51	5 30 0
5	9 3 15		8 41 30		
	1 40 25	5 31 3	2 5 37	5 34 59	5 48 0
	9 21 40		9 4 20		
	2 17 30	5 53 58	2 36 3	5 54 20	6 11 0
6	9 30 25		9 12 37		
	2 28 21	6 12 28	2 43 42	6 11 41	6 29 0
	9 56 34		9 39 40		
	2 51 27	6 30 51	3 6 34	6 29 27	6 45 0
7	10 10 15		9 52 20		
	3 3 4	6 46 19	3 19 5	6 46 12	7 0 0
	10 29 34		10 13 18		
	3 32 30	7 7 35	3 50 41	7 7 11	7 18 0
	10 42 39		10 23 40		
8	3 39 5	7 20 26	3 56 9	7 20 45	7 36 0
	11 1 47		10 45 21		
	4 11 43	7 42 0	4 28 59	7 41 43	7 53 0
	11 12 16		10 54 26		
9	4 21 37	7 58 52	4 38 23	7 58 37	8 19 0
	11 36 7		11 18 51		
	4 53 5	8 19 47	5 11 12	4 18 38	8 36 0
	11 46 28		11 26 4		
10	5 2 18	8 37 51	5 20 7	8 37 34	8 57 0
			11 55 0		
	0 13 23				
	5 37 5	9 1 39	5 56 41	9 1 13	9 10 0
11	0 26 12		0 5 45		
	5 34 15	9 15 19	6 1 25	9 18 22	9 36 0
	0 56 23		0 35 18		
	6 19 33	9 48 4	6 38 42	9 43 26	9 55 0
12	1 16 34		0 48 10		

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
January 12	1 16 34		0 48 10		
	6 19 45		6 37 10		
	1 53 11	10 6 28	1 30 5	10 3 38	10 24 0
	6 40 16		7 2 10		
13	2 19 13	10 29 45	1 55 10	10 28 40	10 45 0
	7 0 10		7 21 16		
	3 7 23	11 3 46	2 43 44	11 2 30	11 17 0
	7 40 5		8 0 10		
14	3 30 10	11 35 7	3 9 24	11 34 47	11 43 0
	8 16 30		8 41 3		
	4 5 55	0 11 12	3 38 46	0 9 55	0 22 0
	9 7 18		9 37 17		
15	4 57 16	1 2 17	4 22 45	1 0 1	0 54 0
	9 41 42		10 6 10		
	5 34 40	1 38 11	5 7 45	1 36 58	1 43 0
	10 16 15		10 46 13		
16	6 6 10	2 11 13	5 43 20	2 14 46	2 20 0
	11 17 28		11 42 47		
	6 43 16	3 0 22	6 18 20	3 0 33	3 3 0
	11 29 30		11 50 20		
17	7 30 20	3 29 55	7 10 30	3 30 25	3 42 0
	0 5 42		0 25 19		
	7 48 45	3 57 14	7 32 12	3 57 45	4 20 0
18	0 46 10		1 2 15		
	8 16 45	4 31 28	7 59 10	4 30 43	4 43 0
	1 25 38		1 39 12		
	8 44 34	5 5 6	8 28 30	5 3 51	5 12 0
19	1 45 21		2 2 40		
	9 25 30	5 35 26	9 8 10	5 35 25	5 37 0
	2 9 50		2 23 25		
	9 33 50	5 51 50	9 19 30	5 51 28	6 14 0
20	2 27 40		2 43 30		
	9 58 21	6 13 0	9 45 34	6 14 32	6 24 0
	3 3 0		3 14 44		
	10 30 15	6 46 38	10 16 30	6 45 37	6 55 0
21	3 10 25		3 24 43		
	10 48 42	6 59 34	10 34 30	6 59 36	7 15 0
	3 53 40		4 7 45		
	10 58 9	7 25 55	10 37 15	7 22 30	7 31 0
22	3 54 11		4 11 41		
	11 22 26	7 38 19	11 9 51	7 40 46	7 56 0
	4 27 10		4 42 48		
	11 35 39	8 1 25	11 22 36	8 2 42	8 4 0
23	4 31 28		4 45 50		
		8 16 4	11 45 54	8 15 52	8 24 0
	0 0 41		5 13 20		
	4 55 15		11 48 32	8 30 56	8 49 0
24	0 15 21	8 35 18	5 16 40		
	4 56 50				
	1 0 12	8 58 31	0 46 29	9 1 35	9 4 0
	5 6 30		5 19 45		
25	0 53 10	8 59 50	0 40 20	9 0 3	9 13 0
	5 28 32		5 48 15		
	1 4 6	9 16 19	0 42 8	9 15 12	9 30 0
	5 56 15		6 17 19		
26	1 48 15	9 52 15	1 23 8	9 50 14	9 47 0

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
January 26	1 48 15		1 23 8		
	5 27 6		5 46 16		
	2 4 3	9 45 35	1 38 55	9 42 36	10 10 0
	6 11 20	10 18 55	6 47 15	10 21 15	10 24 0
27	2 26 30		1 55 16		
	6 32 45	10 36 24	6 58 25	10 32 45	10 43 0
	2 40 3		2 7 6		
	6 54 5	11 18 7	7 27 33	11 4 22	11 0 0
28	3 42 10		2 41 12		
	6 19 50	11 19 30	7 7 45	11 23 28	11 34 0
	4 19 10		3 39 11		
	6 49 56	0 2 0	7 54 50	0 3 29	0 35 0
29	5 14 5		4 12 8		
	8 27 17	0 55 51	9 27 32	1 1 36	1 7 0
	5 24 25		4 35 40		
	9 19 38	1 34 24	10 3 7	1 33 6	1 26 0
30	5 49 10		5 3 5		
	10 18 6	2 39 33	10 49 46	2 36 15	2 3 0
	7 1 0		6 21 45		
	10 32 35	2 45 30	11 0 25	2 44 13	2 45 0
31	6 58 25		6 28 0		
	11 30 30	3 22 58	11 57 50	3 24 10	3 30 0
	7 15 25		6 50 30		
	11 42 35				
February 1					
	8 26 18	4 4 27	0 2 0	4 4 16	3 46 0
	0 2 31		8 6 32		
	8 6 25	4 4 26	0 23 14	4 2 22	4 28 0
2	0 40 35	4 35 58	7 41 30		
	8 31 20		1 2 39	4 37 4	4 48 0
	1 10 8	5 10 14	8 11 30		
	9 10 20		1 29 4	5 9 35	5 17 0
3	1 12 55	5 13 26	8 50 5		
	9 13 56		1 29 16	5 13 10	5 35 0
	1 54 57	5 55 42	8 57 4		
	9 56 27		2 10 19	5 55 52	5 57 0
4	1 32 24	5 47 13	9 41 26		
	10 2 2		1 46 12	5 46 50	6 20 0
	2 36 42	6 11 5	9 47 27		
	9 45 28		2 53 2	6 16 34	6 28 0
5	2 57 50	6 33 10	9 40 7		
	10 8 29		3 10 10	6 32 1	6 43 0
	2 34 38	6 30 32	9 53 52		
	10 26 25		3 51 6	6 59 50	7 13 0
6	3 14 20	7 4 47	10 8 35		
	10 55 14		3 26 31	7 3 50	7 34 0
	3 56 36	7 33 48	10 41 8		
	11 11 0		4 10 17	7 33 33	7 45 0
7	3 57 13	7 47 54	10 56 48		
	11 38 34		4 11 22	7 48 2	8 3 0
	4 15 50	7 59 59	11 24 43		
	11 44 8		4 38 30	8 4 28	8 24 0
8	4 45 40	8 23 44	11 30 27		
			4 59 54	8 22 59	8 43 0
			11 46 4		
	0 1 48				
	5 13 15	8 47 3	5 26 50	8 45 27	9 0 0
9	0 20 51		0 4 3		

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840. February 9	h m s 0 20 51 5 14 10 0 47 26 5 38 9 1 9 20 5 50 17 1 30 0 6 25 2	h m s 9 0 48 9 23 45 9 40 9 10 8 16	h m s 0 4 3 5 29 7 0 30 40 5 54 48 0 55 42 6 5 0 1 8 40	h m s 8 59 54 9 25 15 9 36 50 10 6 47	h m s 9 17 0 9 30 0 10 0 0 10 16 0
10	1 51 31 6 32 50 2 22 54 6 56 12 3 10 15 7 24 30 3 48 18 8 29 35 4 37 15 9 23 34 5 10 30 10 5 15 6 4 32 11 7 48 6 35 40 11 38 2	10 27 52 11 3 13 11 36 24 0 33 25 1 17 2 2 4 54 2 51 44 3 26 17	1 27 30 6 56 40 1 59 11 7 17 40 2 35 0 7 58 0 3 12 37 9 5 10 4 2 48 9 56 19 4 40 50 10 37 20 5 36 16 11 31 2 6 9 35 11 58 26 6 33 45	10 27 55 10 56 20 11 35 39 0 33 59 1 18 34 2 6 48 2 50 19 3 26 11	10 46 0 11 12 0 11 42 0 0 25 0 1 20 0 1 59 0 2 54 0 3 35 0
13	7 14 34 0 22 3 7 40 5 0 43 20 8 5 15 1 21 25 8 35 39 1 35 10 8 56 17 2 11 52 9 16 30 2 23 44 9 39 28 2 59 2 9 48 15 3 9 9 10 11 36 3 36 45 10 24 36 3 35 20 10 42 29 4 7 28 11 0 10 4 15 12 11 14 2 4 34 50 11 24 33 4 38 2 11 47 52 4 55 0 11 57 20 5 2 0	4 1 4 4 24 18 4 58 28 5 15 44 5 44 11 6 1 36 6 23 39 6 40 23 7 0 41 7 8 55 7 33 49 7 43 37 7 59 42 8 12 57 8 26 10	0 41 42 7 20 16 1 0 45 7 50 9 1 38 3 8 18 16 1 56 16 8 41 22 2 27 21 9 1 25 2 37 14 9 25 47 3 13 9 9 35 40 3 23 43 9 58 6 3 51 29 10 9 42 4 0 24 10 27 43 4 22 4 10 36 30 4 29 25 10 58 8 4 49 30 11 7 40 4 52 18 11 32 28 5 9 10 11 37 5 5 17 55	4 0 59 4 25 27 4 58 10 5 18 49 5 44 23 6 1 31 6 24 24 6 40 54 7 0 36 7 14 3 7 29 17 7 43 46 7 58 30 8 12 23 8 23 8	4 16 0 4 39 0 5 10 0 5 28 0 5 50 0 6 11 0 6 34 0 6 52 0 7 12 0 7 30 0 7 43 0 7 59 0 8 10 0 8 22 0 8 41 0
16					
17					
18					
19					
20					
21					
22					
23					

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
February 23	5 2 0		5 17 55 11 50 45	8 34 20	8 52 0
	0 12 30	8 37 15			
	5 15 12		5 35 20		
24	0 34 43	8 54 58	0 25 10	9 0 15	9 2 0
	5 24 12		5 44 50		
	0 41 28	9 2 50	0 15 18	9 0 4	9 20 0
	5 40 47		5 59 4		
25	0 53 52	9 17 20	0 23 12	9 11 8	9 31 0
	5 50 4		6 15 0		
	1 8 42	9 29 23	0 39 3	9 27 2	9 45 0
	6 6 25		6 33 15		
26	1 37 50	9 52 7	0 57 10	9 45 13	10 0 0
	6 26 20		6 58 15		
	1 53 17	10 9 49	1 4 54	10 1 35	10 31 0
	6 59 0		7 51 40		
27	2 48 50	10 53 55	1 49 32	10 50 36	10 57 0
	7 41 53		8 45 48		
	3 56 6	11 49 0	2 42 28	11 44 8	11 42 0
	8 30 5		9 35 50		
28	4 53 16	0 41 41	4 5 34	0 45 42	0 30 0
	10 2 30		10 47 57		
	5 37 52	1 50 11	4 51 10	1 49 34	1 5 0
	10 32 6		11 9 21		
29	6 5 0	2 18 33	5 30 27	2 19 54	2 0 0
	11 29 26				
	6 34 15	3 1 50	0 0 44		
	11 45 0		6 1 17	3 1 4	2 46 0
March 1	6 55 30	3 20 15	0 17 20 6 30 20	3 23 50	3 24 0
	0 30 4		0 58 0		
	7 15 53	3 52 59	6 51 10	3 54 35	4 0 0
2	0 42 50		1 2 25		
	7 40 16	4 11 33	7 19 48	4 11 2	4 23 0
	1 14 12		1 35 28		
	8 5 35	4 39 54	7 50 14	4 42 51	4 48 0
3	1 25 40		1 43 17		
	8 24 25	4 55 8	8 7 12	4 55 15	5 7 0
	1 58 27		2 14 49		
	8 42 20	5 20 24	8 20 5	5 17 27	5 31 0
4	2 9 50		2 24 45		
	9 3 20	5 36 55	8 48 8	5 36 27	5 53 0
	2 40 1		2 54 9		
	9 23 30	6 1 46	9 3 55	5 59 2	6 10 0
5	2 47 42		2 54 21		
	9 47 18	6 17 30	9 35 7	6 14 44	6 32 0
	3 5 57		3 19 1		
	10 4 6	6 35 2	9 51 5	6 35 3	6 50 0
6	3 19 21		3 31 34		
	10 24 10	6 51 46	10 10 29	6 51 2	7 6 0
	3 45 59		3 58 47		
	10 35 45	7 10 52	10 21 30	7 10 9	7 23 0
7	3 59 0		4 12 47		
	10 58 37	7 28 49	10 44 38	7 28 43	7 42 0
	4 22 24		4 36 1		
	11 9 35	7 46 0	10 55 2	7 45 32	7 58 0
8	4 34 41		4 45 15		

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
March 8	4 34 41		4 45 15		
	11 31 11	8 2 56	11 16 12	8 0 44	8 15 0
	4 27 31		5 12 28		
	11 44 52	8 21 12	11 30 15	8 21 22	8 39 0
9	5 15 14		5 29 58		
		8 40 10	11 47 50	8 38 54	8 51 0
	0 5 5		5 32 42		
	5 49 19			8 48 5	9 16 0
10	0 21 55	9 5 37	0 3 28		
	5 53 55		6 11 40	9 17 27	9 36 0
	0 44 43	9 19 19	0 23 14		
	6 8 17		6 27 57	9 37 56	9 51 0
11	1 10 30	9 39 24	0 47 54		
	6 37 51		7 2 14	10 4 36	10 22 0
	1 37 49	10 7 50	1 6 57		
	7 3 20		7 30 25	10 35 14	10 48 0
12	2 6 15	10 34 48	1 40 3		
	7 53 4		8 27 29	11 26 41	11 25 0
	3 4 31	11 28 48	2 25 53		
	8 27 10		9 3 40	0 17 2	0 24 0
13	3 58 16	0 12 43	3 30 23		
	5 53 2		10 28 32	1 24 25	1 18 0
	4 55 16	1 24 9	4 20 15		
	10 12 35		10 40 37	1 56 26	2 0 0
14	5 44 33	1 58 34	5 12 14		
	11 21 32		11 47 30	2 49 0	2 50 0
	6 21 30	2 51 31	5 50 29		
	11 28 15		11 55 6	3 10 23	3 27 0
15	6 47 10	3 7 43	6 25 40		
	0 26 25		0 50 30	3 54 25	3 56 0
	7 22 51	3 54 38	6 58 20		
16	0 40 15		1 0 40	4 12 39	4 25 0
	7 42 6	4 11 11	7 24 37		
	1 17 20		1 35 19	4 41 17	4 50 0
	8 6 3	4 41 42	7 47 15		
17	1 32 9	4 58 49	1 46 40	4 58 26	5 6 0
	8 25 28		8 10 11		
	1 59 32	5 14 56	2 15 6	5 14 38	5 32 0
	8 30 20		8 14 10		
18	2 8 42	5 36 44	2 22 54	5 36 29	5 46 0
	9 4 36		8 50 3		
	2 33 15	5 56 56	2 48 8	5 58 2	6 9 0
	9 20 37		9 6 57		
19	2 39 20	6 8 54	2 49 35	6 6 49	6 21 0
	9 38 28		9 24 2		
	3 4 34	6 27 37	3 19 7	6 27 9	6 43 0
	9 50 40		9 35 10		
20	3 12 20	6 38 56	3 30 40	6 41 0	6 55 0
	10 5 32		9 51 19		
	3 34 15	6 57 25	3 48 21	6 56 46	7 7 0
	10 20 35		10 5 10		
21	3 38 24	7 7 4	3 52 30	7 6 26	7 17 0
	10 35 44		10 20 22		
	3 57 13	7 22 2	4 12 52	7 21 4	7 32 0
	10 46 50		10 29 16		
22	4 10 50		4 26 55		

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
March 22	4 10 50	7 35 13	4 26 55	7 33 43	7 42 0
	10 59 35		10 40 30		
	4 25 10	7 47 43	4 40 50	7 47 57	7 58 0
	11 10 15		10 55 4		
23	4 34 20	7 59 31	4 51 21	7 57 55	8 10 0
	11 24 42		11 4 28		
	4 44 38	8 10 54	5 2 18	8 8 55	8 23 0
	11 37 9		11 15 32		
24	5 4 30	8 24 2	5 27 15	8 22 48	8 38 0
	11 43 34		11 18 20		
	5 10 49	8 36 15	5 32 24	8 32 30	8 49 0
			11 32 35		
25	0 1 40		5 53 20	8 40 24	9 0 0
	5 28 10	8 45 36	11 27 27		
	0 3 1		6 9 30		
	5 42 34	9 9 27	0 0 1	9 4 46	9 20 0
26	0 36 20		6 35 41		
	6 5 25	9 30 38	0 11 39	9 23 40	9 44 0
	0 55 51		6 56 20		
	6 17 10	9 59 43	0 52 23	9 54 22	10 19 0
27	1 42 15		8 17 35		
	7 16 5	10 59 57	1 44 13	11 0 54	11 4 0
	2 43 48		8 46 50		
28	7 45 0	11 37 25	2 33 10	11 40 0	0 3 0
	3 29 50		10 25 43		
	9 36 19	1 10 41	3 58 40	1 12 12	0 41 0
	4 45 2		4 42 55		
	9 46 49	1 32 30	10 25 17	1 34 6	1 26 0
29	5 18 10		4 42 55		
	10 44 15	2 19 43	11 15 20	2 19 50	2 11 0
	5 55 10		5 24 20		
	10 58 30	2 38 28	11 26 11	2 39 41	2 48 0
30	6 18 25		5 53 11		
	11 45 2	3 16 37	0 7 13	3 15 44	3 24 0
	6 48 11		6 24 15		
	11 55 39	3 32 5	0 14 10	3 31 45	3 42 0
31	7 8 30		6 49 20		
		4 3 27	0 52 31	4 3 16	4 16 0
April 1	0 33 49		7 14 0		
	7 33 5	4 21 16	1 0 13	4 20 44	4 39 0
	0 45 0		7 41 14		
	7 57 31	4 48 54	1 28 8	4 48 42	5 0 0
	1 13 3		8 9 16		
2	8 24 45	5 3 35	1 39 11	5 3 57	5 19 0
	1 24 10		8 28 43		
	8 42 59	5 26 12	2 8 21	5 25 7	5 39 0
	1 54 8		8 41 53		
	8 58 15	5 42 40	2 23 30	5 45 56	5 56 0
3	2 4 12		9 8 22		
	9 21 8	6 7 46	2 52 30	6 7 52	6 14 0
	2 38 54		9 23 15		
	9 36 38	6 27 38	3 9 52	6 27 37	6 34 0
4	2 56 44		9 45 22		
	9 58 32	6 46 2	6 31 59	6 45 37	6 58 0
	3 18 58		9 59 14		
	10 13 5	7 6 48	3 52 21	7 6 16	7 12 0
5	3 38 16		10 20 10		
	10 35 20				

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
April 5	3 58 15	7 24 50	4 11 12	7 23 59	7 34 0
	10 51 25		10 36 45		
6	4 17 5	7 47 53	4 31 12	7 47 27	7 54 0
	11 18 40		11 3 44		
	4 29 58		4 44 26		
	11 36 10	8 3 4	11 22 44	8 3 35	8 10 0
7	4 49 15	8 22 32	5 6 14		
	11 55 49		11 35 38	8 20 56	8 33 0
	5 16 28	8 37 19	5 33 42		
	11 58 10		11 47 15	8 40 29	8 54 0
8	5 47 28		6 7 6		
		9 13 51		9 12 12	9 19 0
	0 40 3		0 17 18		
	6 6 20	9 35 52	6 27 30		
9	1 5 24		0 35 43	9 31 37	9 41 0
	6 50 20	10 9 8	7 17 40		
	1 27 55		0 52 41	10 5 11	10 14 0
	7 5 20	10 38 26	7 32 40		
10	2 11 22		1 40 20	10 36 30	10 54 0
	8 10 43	11 35 8	8 48 47		
	2 59 32		2 21 3	11 34 55	11 39 0
	8 34 52	0 10 30	9 5 59		
11	3 46 8		3 13 10	0 9 35	0 11 0
	9 52 9	1 17 36	10 22 48		
	4 43 2		4 10 19	1 16 34	1 14 0
	10 8 22	1 45 0	10 33 57		
12	5 21 37		4 55 44	1 44 51	1 48 0
	10 59 0	2 32 5	11 18 14		
	6 5 10		5 39 16	2 28 45	2 36 0
	11 16 33	2 50 22	11 38 28		
13	6 24 10		6 5 42	2 52 4	3 6 0
	0 1 29	3 29 56	0 20 58		
	6 58 23		6 36 50	3 28 54	3 38 0
14	0 9 25	3 43 56	0 29 50		
	7 18 27		7 1 14	3 45 32	3 57 0
	0 44 34	4 13 55	1 1 36		
	7 43 15		7 24 30	4 13 3	4 24 0
15	0 58 29	4 30 39	1 9 32		
	8 2 48		7 45 53	4 27 43	4 39 0
	1 21 37	4 50 41	1 36 56		
	8 19 45		8 3 13	4 50 5	4 58 0
16	1 36 18	5 4 58	1 50 43		
	8 33 37		8 18 4	5 4 24	5 16 0
	1 59 52	5 21 15	2 15 19		
	8 42 37		8 32 18	5 23 49	5 36 0
17	2 14 50	5 41 15	2 29 55		
	9 7 40		8 51 20	5 40 38	5 54 0
	2 33 38	5 55 59	2 50 14		
	9 18 20		9 2 10	5 56 12	6 9 0
18	2 45 41	6 11 32	2 59 53		
	9 37 23		9 21 57	6 10 55	6 22 0
	2 59 9	6 26 22	3 14 5		
	9 53 34		9 38 45	6 26 25	6 37 0
19	3 12 15	6 40 16	3 22 11		
	10 8 17		9 51 15	6 36 43	6 48 0
	3 21 40	6 52 29	3 38 10		
	10 23 18		10 4 51	6 51 31	7 5 0

TABLE. (Continued.)

	M. ft. in. 9 10	Calculated High Water from M.	N. ft. in. 10 10	Calculated High Water from N.	Observed High Water.
1840.	h m s	h m s	h m s	h m s	h m s
April 20	3 40 52	7 6 49	3 57 3	7 5 32	7 13 0
	10 32 46		10 14 3		
	3 51 52	7 17 54	4 6 53	7 16 10	7 29 0
	10 43 55		10 25 26		
21	4 8 46	7 33 32	4 27 8	7 32 1	7 48 0
	10 58 18		10 36 52		
	4 15 20	7 44 21	4 33 4	7 42 24	7 59 0
	11 13 21		10 51 43		
22	4 41 20	8 2 36	5 2 6	8 0 34	8 18 0
	11 23 52		10 59 1		
	4 42 2	8 13 51	5 2 42	8 11 29	8 28 0
	11 45 40		11 20 15		
23	5 12 20	8 35 14	5 32 12	8 27 18	8 45 0
	11 58 8		11 22 24		
	5 18 23	8 52 37	5 41 29	8 48 2	9 5 0
			11 54 35		
24	0 26 50		6 15 50		
	5 45 7	9 15 44		9 12 4	9 31 0
	0 46 20		0 8 17		
	5 49 29	9 38 8	6 21 11	9 34 38	9 53 0
25	1 26 47		0 48 5		
	6 48 45	10 33 11	7 30 10	10 31 43	10 38 0
	2 17 36		1 33 16		
26	6 58 30	10 54 21	7 42 10	10 53 39	11 11 0
	2 50 12		2 5 8		
	8 39 10	0 9 33	9 24 30	0 10 14	0 5 0
	3 39 55		2 55 58		
27	9 0 5	0 38 38	9 48 12	0 46 46	0 40 0
	4 17 10		3 45 20		
	9 58 31	1 30 37	10 26 15	1 30 12	1 33 0
	5 2 43		4 34 9		
28	10 10 41	1 45 26	10 36 16	1 49 0	2 6 0
	5 20 11		5 1 45		
	11 3 24	2 29 50	11 26 27	2 29 13	2 39 0
	5 56 16		5 31 59		
29	11 21 18	2 49 37	11 44 54	2 49 52	3 7 0
	6 17 55		5 54 52		
	11 59 20	3 23 58	0 19 0		
30	6 48 36		6 29 5	3 24 3	3 33 0
	0 12 30	3 41 38	0 28 16		
	7 10 5		6 54 41	3 41 29	3 54 0
	0 45 16	4 10 28	1 1 22	4 10 49	4 22 0
	7 35 40		7 20 15		

XV.—*Contributions to the Chemical History of Archil and of Litmus.* By ROBERT KANE, M.D., M.R.I.A. Communicated by FRANCIS BAILY, Esq. V.P.R.S., &c. &c. &c.

Received April 30,—Read June 4, 1840.

AMONG the numerous and complex questions as to the constitution of organic substances, which have latterly attracted the attention of chemists, there is scarcely one possessed of more interest to the manufacturer, as well as to the philosopher, and the elucidation of which might better be expected to lead to improved processes in the arts, or to throw more light on difficult points of abstract theory, than the study of the nature and mode of origin of those remarkable colouring materials which form the basis of the archil and litmus of commerce, and which are obtained from lichens of various genera and species, themselves totally devoid of colour.

Although the problem of the origin and nature of these bodies has never been contemplated by chemists in the general point of view, by which alone consequent and satisfactory results could have been arrived at, yet from a very early period in organic chemistry, attention had been directed to isolated portions of it, particularly with regard to litmus, which from its general use as a reagent excited curiosity, and became the subject of frequent, though incomplete examination. Indeed, the nature of litmus appears to have been to many chemists peculiarly obscure, as notwithstanding the researches of FOURCROY and VAUQUELIN, of TENNANT, CHEVREUL, PERETTI, DESFOSSÉS, and many others, BERZELIUS declared in the last year that the chemistry of litmus remained yet to be created. Regarding archil, still less knowledge has been obtained. I am not aware of any writer who has occupied himself directly with its examination; and, indeed, it is only incidentally that HEEREN mentions, in his admirable memoir of the lichen products, any facts belonging to the substance found in commerce.

The origin of those beautiful colouring materials from the different kinds of colourless lichens has, however, formed the subject of extensive and connected investigation, for which we are indebted to HEEREN and to ROBIGNOT; and it will be found useful in the subsequent portions of the present paper, to notice briefly the results to which those eminent chemists arrived. HEEREN analysed particularly the lichens *Parmelia Roccella*, and the *Lecanora Tartarea*. He found therein a peculiar body which he termed Erythrine, as being the basis of the red substances. This erythrine appeared by boiling in alcohol to be changed into another Pseudo-erythrine, and by exposure to the air, into a material soluble in water, which he called Erythrine-bitter. By acting on erythrine or erythrine-bitter with ammonia and exposure to air, there were produced in his experiments three substances, one, yellow, which he did not

further examine; the others, which are red, he termed lichen-red (*Flechtenroth*), and the wine-red, pigment; and, finally, he looked upon the lichen-red as being the colouring material of cudbear and of archil. It is unfortunate that this beautiful series of researches should have been left imperfect, indeed useless as regards the requisitions of organic chemistry at the present day, by there having been no attempt made to ascertain the composition of the numerous substances described by HEEREN, except two analyses by LIEBIG of small portions sent to him by HEEREN, one of the pseudo-erythrine, and the other of a peculiar acid, the roccellic acid, which was found in the *Parmelia Roccella*, but which was looked upon by HEEREN as distinct from those bodies which produce colour. These analyses, although, as might have been expected from the eminence of their author, quite accurate, yet from being isolated and uncontrolled by the analyses of the substances allied to pseudo-erythrine, have remained up to the present day without leading to any further progress in this promising and extensive field; and notwithstanding that there is little doubt of the phenomena having been described by HEEREN with care and exactness, we still remain in total ignorance of the organic changes which produce those phenomena, and of the laws of composition and of mutual reaction which characterize the various substances which he isolated and described. For the purpose, therefore, of establishing a theory of the production of lichen-red from erythrine, no materials whatsoever have been contributed by HEEREN.

The investigations of ROBQUET have led to results which have been found of more direct utility, in illustrating the history of archil, than those of HEEREN. By analysing the *Variolaria dealbata*, ROBQUET discovered therein a substance incapable of producing colour, which he termed Variolarine, and another matter of a saccharoid character, to which he gave the name of Orcine. By means of orceine, the red colour of the archil is produced; this substance ROBQUET also isolated, and gave to it the name of Orceine. Not content with the isolation of these substances, and the description of the phenomena of their production and decomposition, ROBQUET, and subsequently DUMAS, entered upon the analytical investigation of their constitution, in order to determine precisely the manner in which orceine is formed from orceine. The experimental results, however, were such as to admit of different formulæ being proposed, and hence new researches are necessary to ascertain whether the theory of DUMAS or that of LIEBIG, regarding the constitution of orceine, is most correct.

From the preceding sketch of what has been accomplished in this department, it is evident that, as far as concerns the higher objects of chemical investigation, nothing positive or fundamental has been done. Excepting the composition of orceine, no numerical result can be considered as fixed, and consequently no ground whereon to build a theory has been gained. But even in the mere qualitative part of the inquiry, very many questions arise, the solution of which is accompanied by great difficulty. What relation does orceine bear to the colourless substances described by HEEREN? In what relation do the orceine of ROBQUET and the lichen-red of HEEREN stand? Do the various lichens contain the same colourless substances? or do they produce the

same ultimate coloured substance? These are questions which it will be at once seen all preceding researches leave quite untouched, and they must evidently be, at least in great part, solved before any considerable portion of light can be thrown upon this difficult part of science.

I do not pretend to have established in the present paper a complete solution of those difficult questions. In fact, months of continued investigation have proved to me, that the subject is still more complex than the statement above given would point it out to be. If my results appear to have placed the problem of the origin and constitution of these bodies in a more definite light than that in which it had previously been contemplated, and to have shown at least the difficulties of the subject, if not positively to have removed any of them, I shall consider the object for which I now submit to the scientific world these contributions to our knowledge in this department, as sufficiently attained.

The object of the present paper being threefold, viz. first, to ascertain the primitive form of the colour-making substance in a given species of lichen, and trace the stages through which it passes before the coloured substance is developed; secondly, to determine the nature of the various colouring substances which exist in the archil of commerce; and thirdly, the examination of the colouring materials of ordinary litmus; it will be found convenient to divide the paper into three sections under these three heads, and to treat of the subjects in the order above described. Through the kindness of a friend I was enabled to procure, in sufficient quantity, a lichen now used extensively in Liverpool in the manufacture of archil of a very superior kind; this lichen was ascertained by an eminent botanist to be the *Roccella Tinctoria*: it is imported from the Cape de Verd Islands, under the name of archil-weed, and generally sells for 200*l.* per ton: some specimens which I procured were of so fine a quality as to be valued at 320*l.* per ton. The archil and the litmus used in these researches were derived indifferently from various sources in Liverpool, London, and Dublin.

Section I. *Chemical Examination of the Roccella Tinctoria (Archil-weed).*

The treatment to which the lichen should be subjected in order to obtain from it the peculiar principles which it contains, I found after many trials, to be best arranged in the following manner. Having been first chopped very small, it is to be digested in successive quantities of alcohol kept just below boiling (about 140° FAHR.) for some hours, in a retort connected with a condensing apparatus, by which the vaporized portion of spirit may be collected and subsequently used. When by this means all matters soluble in spirit have been dissolved out, the solutions are to be united, and the spirit distilled off in a water bath, until the residue in the retort becomes dry. A mass of a yellowish colour is thus obtained. This mass is to be then boiled in water for a few minutes, and the liquor then filtered as rapidly as possible whilst very hot. What remains undissolved may be again treated by boiling in water, as long as any portion of it appears to dissolve.

The mass insoluble in water is next to be acted on by a weak solution of caustic potash at a temperature of about 100° of FAHR. until it ceases to dissolve. In general but a very small quantity of material remains behind. The alkaline liquor having been carefully filtered, is then to be rendered slightly acid by muriatic acid, a copious greenish yellow precipitate is produced, which must be collected and washed to remove all trace of acid. This substance is then to be dissolved in weak water of ammonia, and mixed with a solution of chloride of calcium in water; any precipitate which forms is to be separated by the filter, and the clear yellowish green liquors again treated by muriatic acid, by which the substance is precipitated, and having been freed from adhering traces of acid by careful washing, it may be considered pure. To this body, as being the origin of the coloured series, I have given the name of *Erythryline*.

The precipitate produced as above described with chloride of calcium, and which is generally formed but in exceedingly small quantity, is to be treated with dilute muriatic acid, which separates a white substance, identical, so far as the small quantity of it at my disposal allowed me to determine, with the *roccellic acid* discovered by HEEREN and analysed by LIEBIG, but as its acid characters are not marked, I would propose for it the more appropriate name of *Roccelline*.

The watery solutions which had been obtained in the treatment of erythryline deposit, on cooling, beautiful crystals, having the appearance of boracic acid. The quantity of these crystals obtained depends on the manner in which the mass has been treated: if the boiling and filtration had been expeditiously carried on, the liquor often solidifies from the quantity of crystals which separate on cooling, but if the process had been slowly carried on, very little is obtained. These crystals having been removed, no more can be obtained by evaporating the liquors in which they had been formed, and if a liquor containing crystals be heated so that they redissolve, but very few again appear on the liquor being allowed to cool. This crystallized body, on examination, is found to be identical with the *pseudo-erythrine* discovered by HEEREN and analysed by LIEBIG; but as it will be hereafter shown that this body is not the accidental product which HEEREN considered it to be, but in reality one of the most important in the series, and that there is very great reason for supposing the *erythrine* of HEEREN to have been a mixture of other bodies, I believe that I am justified in transferring to this body the name *erythrine*, as certainly the word *pseudo* was attached to it by HEEREN under a misconception.

The watery solution, from which the crystallized erythrine has been deposited, is always more or less brown coloured. When evaporated in a water bath, it gives a semifluid brownish mass, which can scarcely be rendered quite solid by any temperature below that of incipient decomposition. The circumstance of this substance being formed from erythrine, its great solubility in water, and its peculiar bitterish taste, show it to be the erythrine-bitter of HEEREN. This name, being well enough suited to our language, I shall retain.

When a strong solution of erythrine-bitter is exposed to the action of the air for

a considerable time, as, for some months, it is gradually converted into a mass of soft granular crystals, which by washing with strong cold alcohol may be obtained completely white. This crystalline material constitutes the last gradation in the series of bodies arising from erythryline, and as indicative of its position, I propose to distinguish it by the name *Telerythrine*. The word $\tau\epsilon\lambda\omicron\varsigma$ indicating the termination, as the word $\epsilon\lambda\gamma$ indicated the commencement, of the series.

There are thus found either pre-existing in the lichen *Roccella Tinctoria*, or produced immediately by the processes employed in its analysis, the following bodies:

- 1st. Erythryline.
- 2nd. Erythrine. Pseudo-erythrine of HEEREN.
- 3rd. Erythrine-bitter.
- 4th. Telerythrine.
- 5th. Roccelline, roccellic acid of HEEREN.

Generally speaking, these substances are identical with those found by HEEREN in the *Parmelia Roccella* and the *Leucanora Tartarea*; the ultimate production of telerythrine having escaped his notice, and, as I believe, his erythrine having been erythryline in an impure form mixed with other substances.

It is singular, however, that these substances are all different from those found by ROBIGNET in the *Variolaria dealbata*. I could not find in the lichen I examined a trace of variolarine or oricine, and certainly the *Variolaria* could not have contained either erythryline or erythrine without their having been recognized by ROBIGNET. We may consequently infer that there exist in the lichens which yield purple colours at least two groups, characterized by different active principles, but, as shall be hereafter shown, ultimately generating by their decomposition the same coloured substance; the archil from these various lichens being for the purposes of the arts identical, and containing in reality the same substance, orceine.

The lichen which has been exhausted by boiling alcohol and has furnished the substances above described, yields to boiling water only a small trace of starch and gummy matter. What then remains is merely woody fibre and some earthy salts.

I shall now proceed to the description of the properties and constitution of these substances in detail.

I. Of Erythryline.

This substance when first prepared, and particularly when the preliminary operations are rapidly conducted, is of a pale yellowish colour, often nearly white, which colour I consider, from the appearance of the plant, it should have if completely pure. It is more frequently, however, of a greenish tinge, arising, as I believe, from a very minute trace of chlorophyl, which attaches itself to it and accompanies it in all its reactions. From this trace of chlorophyl I do not know any mode of freeing it, but the quantity is so minute that I did not find specimens of erythryline of very different shades to differ from one another in composition in a greater degree than might and frequently does occur in different analyses of the same pure substance.

Erythryline is insoluble in water, cold or hot, but by boiling with water it is gradually altered, and the liquor is then found to contain erythrine-bitter. It is easily soluble in alcohol and in ether. It is soluble in alkaline liquors, from which it is precipitated on the addition of an acid. It combines with metallic oxides by way of double decomposition, forming salts or lakes, which are generally greenish coloured. It does not appear to possess acid properties, however; its alkaline solutions cannot be obtained in any form neutral to test paper; and I therefore think it better not to give to its name any form which acids are generally characterized by.

When heated, erythryline fuses a little above 212° , and on a further application of heat it is decomposed without any trace of tendency to volatilize.

Its analysis was effected as follows:

A. 0.358 gramme of material gave 0.878 gramme of carbonic acid, and 0.262 of water.

B. 0.407 gramme of material gave 0.987 gramme of carbonic acid, and 0.307 of water.

These results give the composition in 100 parts.

	A.	B.	
Carbon . . .	67.83	67.06	} 100.00
Hydrogen . .	8.13	8.37	
Oxygen . . .	24.04	24.57	

Leading to the formula $C_{22}H_{16}O_6$, which gives

22 Carbon . . .	134.2	67.71
16 Hydrogen . .	16.0	8.07
6 Oxygen . . .	48.0	24.22
	198.2	100.00

By mixing a solution of erythryline in ammonia, in which the alkali was as little as possible in excess, with a solution of nitrate of lead, and washing the precipitate until all impurities had been removed, there was obtained a pale greenish powder, which was dried at 212° FAHR. and then analysed.

A. 0.739 gramme of material gave by BERZELIUS' method 0.163 gramme of metallic lead, and 0.213 gramme of oxide of lead.

B. 0.710 gramme of material gave 0.811 gramme of carbonic acid, and 0.251 gramme of water.

The formula which results is $C_{22}H_{16}O_6 + 2 PbO$. Thus

	Theory.		Experiment.
22 Carbon =	134.2	31.85	31.58
16 Hydrogen =	16.0	3.79	3.92
6 Oxygen =	48.0	11.39	11.90
2 Oxide of lead =	223.2	52.97	52.60
	421.4	100.00	100.00

It might appear much simpler to consider the formula of this substance as being but half of the above, $C_{11} H_8 O_3$, and the lead salt as $C_{11} H_8 O_3 + PbO$. But it will be seen that circumstances connected with the other substances of this series show that the equivalent contains the larger formula. A more important objection to which the formula just given is exposed, arises also from the constitution of many of the bodies to be afterwards described, that the number of equivalents of hydrogen is not sixteen but fifteen. The grounds of this supposition shall be hereafter noticed, and for comparison I will here insert the result calculated on that idea.

22 Carbon . . .	134.2	68.06
15 Hydrogen . . .	15.0	7.60
6 Oxygen . . .	48.0	24.34
	197.2	100.00

The value of the carbon is but slightly altered, but the difference of hydrogen is very great; if the true value for hydrogen be fifteen atoms, then in one case there was 0.67 of hydrogen obtained too much. Notwithstanding this some may be inclined to adopt this number.

II. Of Erythrine.

This substance being the pseudo-erythrine of HEEREN, has been very determinately characterized by that chemist in his description of its properties. It is but very sparingly soluble in cold water; in boiling water, on the contrary, it dissolves in great abundance, and on cooling separates under the form of micaceous plates of considerable lustre. Its fresh solution in water is colourless, but if it be kept for a little time exposed to the air, particularly when hot, it rapidly becomes brown, still remaining, however, clear and transparent. The erythrine is then wholly, or in great part decomposed, and on cooling little or no deposition of crystals occurs.

Erythrine is very soluble in alcohol and ether; also in alkaline solutions, from which, however, it is precipitated unchanged on the addition of an acid. If its alkaline solutions be exposed to the air, they become coloured after a little time, brown with potash or soda, but wine-red if the alkali be ammonia.

At a temperature of about 220° FAHR., erythrine fuses without losing water. When further heated it is decomposed, giving the usual products of unazotized organic matter, without any portion being volatilized.

It does not precipitate any neutral metallic solution. If a solution of erythrine in ammonia be added to nitrate or acetate of lead, a copious white precipitate falls, which contains erythrine, and which was subsequently analysed.

To determine the composition of erythrine, the following analyses were made.

A. 0.428 gramme of material gave 0.947 gramme of carbonic acid, and 0.239 gramme of water.

B. 0.347 gramme of material gave 0.769 gramme of carbonic acid, and 0.194 of water.

From these results, the numbers which follow, and to which I will annex the result obtained by LIEBIG, with the specimen of pseudo-erythrine sent to him by HERRN, are deducible, and they point to the very simple formula $C_5 H_3 O_2$, the calculated results of which are likewise added.

Experiment.	A.	B.	LIEBIG.
Carbon . .	61.19	61.16	60.810
Hydrogen . .	6.20	6.31	6.334
Oxygen . .	32.61	32.53	32.856

} 100.00

The theoretical numbers being,

5 Carbon . .	30.5	61.73
3 Hydrogen . .	3.0	6.04
2 Oxygen . .	16.0	32.23
	49.5	100.00

The formula deduced by LIEBIG was almost identical, it being $C_{20} H_{12.5} O_8$.

The compound of erythrine with oxide of lead was found to give the following results.

A. 0.970 gramme gave 0.152 gramme of oxide of lead, and 0.585 gramme of metallic lead.

B. 1.088 gramme gave 0.468 gramme of carbonic acid, and 0.129 gramme of water.

The simplest formula expressing these results, is $C_5 H_3 O_2 + 2 PbO$, which gives

	Theory.		Experiment.
5 atoms Carbon . .	30.5	11.18	11.89
3 atoms Hydrogen . .	3.0	1.10	1.32
2 atoms Oxygen . .	16.0	5.87	6.20
2 atoms Oxide of lead	223.2	81.85	80.59
	272.7	100.00	100.00

The quantity of oxide of lead in this analysis varies more from the calculated result than in other cases it was found to do, the quantity of oxide of lead being generally between 81 and 82 per cent. The specimen analysed was prepared with as little alkali as possible, and hence probably a small quantity of erythrine in excess at once gave too high a value for the constituents of the organic element, and reduced the oxide of lead below the proper amount.

Although the very simple formula $C_5 H_3 O_2$, expresses so accurately the constitution of erythrine in its free as in its combined condition, yet some consideration is necessary before finally adopting it. The erythrine, as proved as well by the experiments of HERRN as by my own, is but one member of a series of bodies arising from the erythryline, and hence there must be established formulæ, not merely exhibiting the numerical results of analysis, but also displaying the manner in which these bodies are produced, one from the other, before their history can be considered as complete. If we compare therefore the formulæ of erythryline and of erythrine as just now given,

$C_{22}H_{16}O_6$, and $C_5H_4O_2$, or $C_{20}H_{12}O_8$, there does not appear any very simple mode by which they can be connected, and I am consequently disposed to look upon the erythrine as containing in its equivalent the same quantity of carbon as exists in the erythryline, and assigning to it consequently the formula $C_{22}H_{13}O_9$, connected with that of erythryline by the substitution of three equivalents of oxygen for three equivalents of hydrogen. If erythryline be $C_{22}H_{15}O_6$, then erythrine will be $C_{22}H_{12}O_9$, to which, however, as will be seen from the annexed calculated results, the value of the hydrogen is not easily reconciled.

C_{22}	=	134.2	61.22	C_{22}	=	134.2	61.503
H_{13}	=	13.0	5.93	H_{12}	=	12.0	5.500
O_9	=	72.0	32.85	O_9	=	72.0	32.997
		219.2	100.00			218.2	100.000

On either of these formulæ the constitution of the lead salt agrees with experiments very satisfactorily; thus

C_{22}	=	134.2	12.05
H_{13}	=	13.0	1.17
O_9	=	72.0	6.47
8 PbO	=	892.8	80.31
		1112.0	100.00

The difference between 12 and 13 of hydrogen is here insensible.

It is an exceedingly interesting question to judge if the original erythrine of HEEREN should be looked upon as a determinate and independent substance, or whether it should be considered as having been, under an impure form, any of the substances which I have found. The accuracy and detail with which HEEREN operated upon the substances he describes, should certainly be considered as rendering it highly improbable that he could have examined his erythrine in such a variety of ways, without detecting it to be a mixture, if it really was so; and more, he assigns to erythrine two characters which certainly do not belong to either of the bodies which I have now described; 1st, that it is insoluble in ether; and 2nd, that when heated it is in part volatilized. On the other hand, if he had obtained the erythrine in a pure condition, it is not likely that he would have sent his pseudo-erythrine to LIEBIG for analysis, without sending also the substance, which was the far more important of the two, his erythrine; this point is strengthened also by the fact that he found the active principle of the *Lecanora Tartarea* to be by no means identical with, although strongly resembling erythrine. The conversion of his erythrine also into pseudo-erythrine by boiling with alcohol, indicates either the identity of erythryline with his erythrine, which can scarcely be supposed, or that his erythrine was a mixture of true erythrine with some other substances more sparingly soluble in alcohol and scarcely soluble in ether, which I consider to have been most probably

the fact. The difficulty might be got rid of, by supposing that the three lichens *Rocella Tinctoria*, *Parmelia Rocella*, and *Lecanora Tartarea*, all contained primitively different characteristic bodies, which possessed the common character of generating his pseudo-erythrine, and the bodies which result from its decomposition; but, although in a certain degree supported by the analogy of the *Variolaria dealbata*, which contains orcline and no erythrine, I consider this idea as being much less likely to be true, than that the erythrine of HEEREN should be found to have been a mixture. It is on these grounds that I have transferred the name erythrine to his pseudo-erythrine, the substance which has been just now described.

III. Of Erythrine-bitter.—Amarythrine.

The substance which I shall now proceed to describe, is that which forms when erythrine is dissolved in hot water and exposed for some days to the action of the air. Its existence was recognised fully by HEEREN, and I only propose the modification of his name as being in some degree more consonant to the principles of nomenclature in the English language.

The amarythrine has a very peculiar bitter sweet taste, which, as well as its odour, resembles that of burned sugar. It is exceedingly soluble in water, much less so in alcohol, and not at all in ether. Its affinity for water is such, that it cannot be obtained in a solid form without partial decomposition. Exposed in vacuo over concentrated sulphuric acid, it shows no tendency whatsoever to solidify, and remains in a stove at a temperature of 200° FAHR. for weeks perfectly liquid. If heated in an oil bath or over a lamp, the water may be expelled, but the brownish mass obtained is so evidently altered as to be unfit for analysis.

The solution of amarythrine in water is of a pale brown colour, perfectly neutral to test paper. With the ordinary metallic salts it yields precipitates, which are, when dried, of a reddish brown colour. The constitution of these salts is perfectly definite, and hence by means of them the composition of the amarythrine may be completely ascertained. The truly definite nature of the salts of amarythrine is fully shown by the fact, that the precipitate which first forms when a solution of nitrate of lead is precipitated by amarythrine, and the second portion which is produced when the acid supernatant liquor is neutralized by ammonia, were found to possess precisely the same composition. The amarythrate of lead was analysed as follows:

A. 0.491 of the precipitate formed by amarythrine in a solution of nitrate of lead, the liquor being acid, gave

0.208 of oxide of lead, and 0.015 of metallic lead.

0.565 of the same substance gave 0.569 of carbonic acid, and 0.151 of water.

B. 0.970 of the precipitate produced by neutralizing the acid liquor of A. gave 0.963 of carbonic acid, and 0.238 of water.

1.122 of the same substance gave 0.237 of oxide of lead, and 0.260 of metallic lead.

These substances had been dried at 212° in LIEBIG'S drying apparatus with a current of air.

These results give the composition in 100 parts :

A.		B.	
Carbon . . .	27.92	27.46	} 100.00
Hydrogen . . .	2.96	2.72	
Oxygen . . .	23.50	23.92	
Oxide of lead . .	45.62	45.90	

The simplest formula by which these results can be expressed is $C_{11}H_6O_7 + PbO$, which is very simply related to that of erythryline, $C_{11}H_8O_3$. To show, however, the connexion between erythrine and erythryline, the number of equivalents of carbon is taken as twenty-two, and then the origin of the amarythrine becomes extremely simple. The erythrine being $C_{22}H_{13}O_8$, the amarythrine is $C_{22}H_{13}O_{14}$, being formed by the absorption of five equivalents of oxygen. The calculated results of both formulæ are subjoined.

11 Carbon . .	67.1	27.88	22 Carbon . .	134.2	27.805
6 Hydrogen . .	6.0	2.49	13 Hydrogen . .	13.0	2.690
7 Oxygen . .	56.0	23.26	14 Oxygen . .	112.0	23.225
Oxide of lead . .	111.6	46.37	2 Oxide of lead . .	223.2	46.280
	240.7	100.00		482.4	100.000

Both agree well with experiment; the latter, however, best.

IV. Of Telerythrine.

When the semifluid amarythrine is exposed for a long time (several months) to the action of atmospheric air, it gradually changes into a mass of very minute granular crystals of a brownish yellow colour. These are very soluble in water, but less soluble in alcohol, by means of which they may, without much loss, be washed from adhering portions of unaltered amarythrine, and so obtained almost completely white. They can scarcely be purified by re-crystallization, as if re-dissolved in water the solution may remain for a long time before it again forms crystals. It is insoluble in ether.

The telerythrine is neutral to test paper. It combines with metallic oxides, forming precipitates which are very nearly quite white. Its taste is sweetish bitter. Ammonia acts on it much less rapidly than on the body last described, but ultimately the ammoniacal liquor becomes deep wine-red.

The following analyses were made of crystallized telerythrine dried carefully by pressure between folds of blotting paper, but without exposure to heat.

A. 0.506 of substance gave 0.819 of carbonic acid, and 0.172 of water.

B. 0.473 of substance gave 0.775 of carbonic acid, and 0.156 of water.

These results indicate the formula $C_{22}H_{10}O_{19}$, and give the per cent. composition, which, with the theory, follows.

	Theory.		Experiment A.	Experiment B.
22 Carbon . . .	134.2	45.31	44.79	45.35
10 Hydrogen . .	10.0	3.37	3.78	3.67
19 Oxygen . . .	152.0	51.32	51.43	50.98
	296.2	100.00	100.00	100.00

These crystals were afterwards exposed to a current of dry air at 212° FAHR. in LIEBIG's drying apparatus, but did not lose any water.

To determine the constitution of the salts of telerythrine, the precipitate produced by it in a solution of sub-acetate of lead, having been dried at 212° , was analysed.

A. 1.180 gramme of material gave 0.691 of metallic lead, and 0.037 of oxide of lead.

1.982 gramme of same substance gave 1.097 of carbonic acid, and 0.230 of water.

B. Another portion was afterwards prepared by the same means: of it

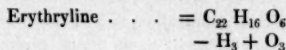
1.124 gramme gave carbonic acid 0.628, and water 0.158.

1.162 gramme gave oxide of lead 0.127, and metallic lead 0.604.

These results lead to the formula $C_{22}H_9O_{18} + 5 PbO$, and the composition per cent. is

	Theory.		Experiment A.	Experiment B.
22 Carbon . . .	134.2	15.88	15.29	15.46
9 Hydrogen . . .	9.0	1.07	1.30	1.56
18 Oxygen . . .	144.0	17.04	17.22	15.94
5 Oxide of lead . .	558.0	66.01	66.19	67.04
	845.2	100.00	100.00	100.00

The telerythrine is produced, therefore, from the amarythrine by the removal of four equivalents of hydrogen and the absorption in their place of four equivalents of oxygen; and the complete series of reactions which I have pointed out hitherto may be thus expressed:



In this manner it appears, therefore, that the changes in the constitution of the substances primitively existing in the *Rocella Tinctoria* proceed when exposed simply to the oxidizing agency of the air. In every one of these stages they are capable of

giving by treatment with ammonia the wine-red substance, which is the commencement of the archil series. It is, however, the amarythrane which most rapidly and most perfectly produces that result. The exact nature of the products of this interesting process will next be studied as they exist in the archil of commerce prepared from the species of lichen, the simpler changes of whose characteristic ingredients we have now examined.

Section II.—*Chemical examination of the Archil (Orseille) of Commerce.*

The archil which I made the subject of experiment, is prepared by treating in the usual manner by means of impure ammoniacal liquors, the lichen already described, previously ground down to a pulpy form. The complete production of archil requires considerable time, and indeed it will be hereafter shown, that archil is always in a transition from one stage to another, and that in these various conditions the nature of its colouring material is completely different.

To separate the substances contained in archil, the following process was ultimately found the most successful. A quantity of archil was rendered slightly acid by muriatic acid, and then evaporated cautiously to perfect dryness. The dry mass was boiled in spirit until this came off but very slightly coloured. The alcoholic liquors were then all mixed together and distilled in a water bath to dryness, by which a deep crimson mass was obtained. This was then powdered and washed with cold water until all traces of sal-ammoniac had been removed, the powder then dried and digested in warm sulphuric ether as long as this fluid became very sensibly coloured. After the action of the ether, the last traces of it having been removed by exposure to a temperature of 212° for a couple of hours, the proper colouring substance of the archil remains as a fine crimson powder. Of this substance there are two different modifications, of which one constitutes the orceine of ROBIGNET and DUMAS, and the other being very closely allied to it, I shall distinguish them by the terms *Alphaorceine* and *Betaorceine*, retaining the word *Orceine* as a kind of generic term for both.

The ethereal solutions, which are of a fine crimson colour, are next to be distilled in a water bath to dryness. A semifluid mass remains, of an oily nature, staining paper, and liquifying completely at a moderate heat. On standing for a few days, a little orceine gradually separates from it, and in order more certainly to free it from traces of that substance, it should be dissolved in the smallest possible quantity of ether, the solution decanted from the powdery orceine which remains undissolved, and then evaporated, at first at a very moderate heat, but ultimately being kept at 212° for a long time, in order to be certain that the last portions of ether had been expelled. The substance thus obtained is still not always simple, but the peculiar characteristics of it shall be hereafter described. I give to it the name of *Erythroleic acid*.

The mass which resisted the solvent action of the alcohol should next be boiled in water repeatedly. At first the liquor becomes pink from traces of orceine, which

the alcohol had not taken up. There then dissolves a substance which colours the water golden yellow, and there remains a dark red substance, apparently insoluble in water. The yellow colour imparted to the water cannot be due to any minute portion of this substance, for when the yellow liquor is evaporated, it leaves a film of solid material, which is not red, as should be the case, but yellow. The yellow substance is therefore probably a peculiar material, most likely the yellow material (*gelbe materie*) of HEEREN, but from the minute traces of it which I could obtain, I could not make any additions to its history further than that the alkalies did not appear to alter its colour. The substance insoluble in water has still to be separated from a quantity of vegetable fibre, arising from half decomposed shreds of lichen, and from some earthy matters with which it is mixed. For this purpose it is to be boiled with a weak solution of caustic potash, in which it rapidly dissolves. The solution is wine-red coloured, without a shade of purple. On neutralizing the solution by an acid, there does not take place any precipitation; but if the solution be then evaporated to dryness, and then washed until all the salt of potash is removed, the substance remains pure, as far as the experiments I have instituted with it could indicate. To this substance, from considerations which will hereafter appear, I give the name of *Azoerythrine*.

The archil of commerce is thus found to consist essentially of three ingredients, orceine, erythrolic acid, and azoerythrine; of each of the two former there exist two modifications, which will shortly be described; and there is in addition, the yellow matter. It is important to determine now, how far these results agree with those obtained by HEEREN, in examining the products evolved by his erythrine in contact with air and with ammonia.

1st. In all properties given by HEEREN, his lichen-red (*flechtenroth*) identifies itself with orceine.

2nd. The azoerythrine assimilates itself to the wine-red pigment of HEEREN, in the characteristic property of not being coloured violet by alkalies. He appears, however, to consider the wine-red pigment as being soluble in water, whilst in reality it is its combination with an alkali that is so. As he operated on a solution in ammonia, there is every reason to look upon the substances as identical.

3rd. The yellow substance is mentioned by HEEREN only incidentally, and no comparison can be instituted.

4th. HEEREN did not meet with the erythrolic acid; indeed, operating on erythrine, he could not meet with it, as it shall be hereafter shown to have its origin in a substance of a totally different nature.

The researches of HEEREN, having thus to a great extent anticipated my results as to the constitution of archil, it may be necessary for me briefly to justify the change that I have made in his nomenclature. The word lichen-red would be certainly a much better name for that substance than orceine, since orceine is not the only primitive material capable of yielding it; but the word Orceine has become by the

labours of ROBIGNOT and DUMAS so fixed in scientific language, that very few persons would go back to lichen-red, which in addition does not adapt itself so well to the structure of English or French nomenclature as orceine. The word wine-red pigment is one which could not conveniently be retained in any scientific language; it is totally unfit for expressing the classes of compounds which this substance forms; and as I shall have occasion soon to show that this body is connected in a very interesting manner with the erythrine series, the name azoerythrine appears to me one of the least objectionable possible.

In analysing the substances of this group which contain nitrogen, the usual precautions were taken to avoid the source of error arising from the formation of nitric oxide. In every instance, three inches of the anterior of the tube were occupied by clean metallic copper, in the form either of thin sheet clippings, or coarse powder freshly reduced by hydrogen. In other respects, the analyses were conducted in the manner which has been already described.

I. Of *Azoerythrine*.

Although at first sight there appears to be a considerable quantity of the solid material of archil insoluble in spirit, yet when the process already described has been followed out, the portion of pure azoerythrine is found to be exceedingly minute, so that it is necessary to operate upon a considerable quantity of archil in order to obtain sufficient for the purpose of analysis. As prepared from different portions of archil, however, its properties appear to be sensibly the same.

These properties may be deduced in great part from what has been already said. Insoluble in water, in alcohol, and in ether, it dissolves in alkaline liquors, giving the characteristic port wine colour. This solution is not precipitated by acids. With solution of acetate of lead and other metallic salts it gives brownish red precipitates. Heated, it gives water and other pyrogenic products, but neither melts nor does it volatilize; nor was I able to detect among the products of the action of a moderately high temperature upon it, any orceine, as should be found according to HEEREN's statement, that his wine-red pigment, when heated, gives off a vapour free from azote, and produces lichen-red. The quantity of material at my disposal was however so very small, that I do not at all consider HEEREN's statement as being destitute of truth.

The analysis of this substance is liable to difficulty, on account of the possible existence in it of traces of another substance, equally insoluble in alcohol, and very sparingly soluble in water, and which, although properly a constituent of litmus, yet occasionally is to be found in archil, although in very minute quantity. This foreign substance (azolitmine) which shall be hereafter described, is turned blue by alkalis, and hence whenever the alkaline solution of azoerythrine possesses any slight bluish or violet tinge, it may be inferred to be contaminated by the presence of azolitmine, and consequently unfit for being used for obtaining numerical results.

A specimen of azoerythrine, which I had every reason to look upon as being completely pure, was analysed.

0.300 gramme of substance dried at 212° gave 0.421 gramme of carbonic acid, and 0.154 of water.

To determine the quantity of nitrogen, the method of estimating the relative volumes of the carbonic acid and the nitrogen gases was adopted, in preference to the method of absolute determination, because I was perfectly certain of the relative accuracy of graduation of the tubes which I employed, but I could not be so certain of their absolute exactness. The following numbers express the result of an experiment of this kind, made with every precaution for avoiding error.

Tube.	$\text{CO}_2 + \text{N.}$	N.	$\text{CO}_2.$	N : $\text{CO}_2.$
A.	464	gave 21 and 443.		$\therefore 1 : 21.1$
B.	205	gave 9 and 196.		$\therefore 1 : 21.8$
C.	242	gave 11 and 231.		$\therefore 1 : 20.0$
D.	359	gave 17 and 342.		$\therefore 1 : 20.1$

In an experiment of this kind all sources of error tend to increase the quantity of nitrogen in relation to the carbon, and hence I consider the numbers above given as rendering it highly probable that the true proportion is one of nitrogen to twenty-two of carbon, and on this idea the analysis leads to the formula $\text{C}_{22} \text{H}_{19} \text{N O}_{22}$, giving

	Theory.		Experiment.
22 Carbon . .	134.2	39.09	38.80
19 Hydrogen . .	19.0	5.53	5.70
22 Oxygen . .	176.0	51.27	55.50
1 Nitrogen . .	14.1	4.11	
	343.3	100.00	100.00

A portion of a brownish red compound of azoerythrine with oxide of lead, prepared by mixing a solution of azoerythrine in potash water, rendered very nearly exactly neutral by acetic acid, with a solution of tribasic acetate of lead, was analysed as follows, having been previously dried at a temperature of 180° .

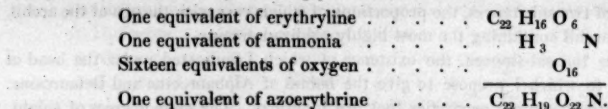
0.657 gramme gave 0.456 of carbonic acid, and 0.177 of water.

0.746 gramme gave 0.112 of metallic lead, and 0.251 of oxide of lead.

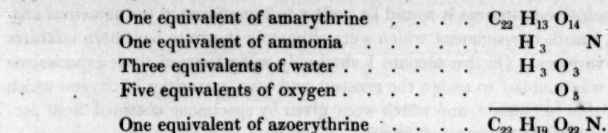
These results are expressed by the formula $\text{C}_{22} \text{H}_{19} \text{N O}_{22} + 3 \text{ Pb O}$, by which is obtained

	Theory.		Experiment.
22 Carbon . .	= 134.2	19.79	19.33
19 Hydrogen . .	= 19.0	2.80	3.00
22 Oxygen . .	= 176.0	28.03	27.88
1 Nitrogen . .	= 14.1		
3 Oxide of lead =	334.8	49.38	49.79
	678.1	100.00	100.00

These numbers are confirmatory of the constitution of the substance as analysed when uncombined, and hence the formula given above may be looked upon as well established, although the number of analyses was limited to those above given, from the very small quantity of the substance which I obtained in a sufficiently pure condition. The connexion of this formula with that of the erythrine series is at once seen from the permanence of the twenty-two atoms of carbon which characterize that group of bodies, among which the erythryline appears to be that from which the azoerythrine is most directly and simply formed, in fact



To explain the formation of azoerythrine from amarythrine, which is the highest member of the erythrine series by which we can consider it to be produced, we must suppose three equivalents of water to become fixed in the substance, thus :



The fixation of these three equivalents of water in a form not capable of being separated by combination with oxide of lead, appears to me not very likely, but if they could be eliminated, and that the formula of dry azoerythrine became $C_{22} H_{16} O_{19} N$, a difficulty in the theory of the production of orceine would be removed, the nature of which will hereafter be pointed out. It is possible that the analysis of a more basic salt of lead, or of a salt of silver, might demonstrate that these three equivalents of water may be replaced, or that even by a higher temperature they might be removed.

II. Of Orceine.

This substance, as prepared by the process already described, is of a fine red colour, very sparingly soluble in water, which however it colours a very beautiful pink, and from which it is precipitated totally on the addition of any soluble neutral salt. It is copiously soluble in alcohol, the solution being of a splendid crimson colour, and being precipitated by the addition of water. It is but very sparingly soluble in ether. Orceine dissolves easily in a watery solution of potash or of ammonia, giving a magnificent purple liquor, the colour of ordinary archil, from which the colouring matter may be totally removed by the addition of an excess of common salt. An alkaline orceinate gives with metallic salts, lakes of very beautiful purple of various shades, which however lose a great deal of their lustre on being dried.

On commencing the analysis of this substance, I was met by a degree of discord-

ance and irregularity in my results, which at once showed me that specimens obtained at different times from different portions of archil had totally different elementary constitutions. I soon found, however, that this difference fell altogether upon one constituent, the oxygen, for it appeared that the carbon, hydrogen, and nitrogen were always in the same proportion to each other, but that the amount of oxygen present in the substance was liable to variation. At length, after a numerous series of analyses, I was enabled to assign the limits within which the variations were included, and to satisfy myself that the orceine, as prepared from archil, is in most cases a mixture of two substances, the proportions of which vary with the age of the archil, the oldest archil containing the most highly oxidized orceine.

These are the substances, the existence of which I indicated under the head of archil, and to which I propose to give the names of Alphaorceine and Betaorceine. In all essential chemical properties they are identical. The same degrees of solubility in water, in alcohol, and in ether; generating the same purple liquor with the alkalis, and the same purple coloured lakes with metallic oxides; and in all cases to be distinguished from each other by the results of their ultimate analysis alone.

Under such circumstances it would be useless to bring forward the numerous analyses which I made of specimens, which were ultimately shown to have been mixtures of the two varieties. On this account I shall only bring forward those experiments by which I was enabled to assign the greatest and least quantities of oxygen which orceine is liable to contain, and which were given by specimens obtained from portions of archil differing very much in age.

For the determination of the azote, however, although variable mixtures were employed, the results were always satisfactory; indeed the relation of the carbon to the nitrogen being the same in both varieties, the relative volumes of nitrogen and carbonic acid, determined by the method which I followed, was the same as if perfectly pure specimens of either were employed, and the results which follow were obtained by the combustion of ordinary mixed orceine.

Tube.	CO ₂ + N.	N.	CO ₂ .	N. : CO ₂ .
A.	600	31.4 = 568.6	∴	1 : 18.1
B.	151	7.8 = 143.2	∴	1 : 18.3
C.	552	28.3 = 523.7	∴	1 : 18.5
D.	373	19.0 = 354.0	∴	1 : 18.6
E.	226	11.5 = 214.5	∴	1 : 18.7

These results, which agree unusually well with each other, fix the relation of carbon to azote as eighteen atoms of the former to one of the latter. This is the same proportion which LIEBIG assigned from considerations on the production of orceine from orcine, and hence the proportion of sixteen to one, assigned by DUMAS from his analysis of orceine, was thrown rather too low. The difference in the proportion of azote per cent., on the supposition of eighteen to one, or of sixteen to one, not being quite 0.5 per cent., and hence being completely included within the limits of error unavoidable in so difficult a process.

I will now proceed to describe the analyses which were made of the two forms of orceine and of their salts.

A. Analysis of Alphaorceine.

A. 0.302 gramme of substance gave 0.829 of carbonic acid, and 0.192 of water.

B. 0.417 gramme gave 0.950 of carbonic acid, and 0.229 of water.

These results lead to the formula $C_{18}H_{10}NO_5$, giving

	Theory.		Experiment A.	Experiment B.
18 Carbon . . .	109.8	63.14	63.32	63.04
10 Hydrogen . .	10.0	5.75	5.89	6.11
1 Nitrogen . . .	14.1	8.11		
5 Oxygen . . .	40.0	23.00	30.79	30.85
	173.9	100.00	100.00	100.00

A solution of alphaorceine in ammonia was decomposed by acetate of lead, and the mixed liquors rendered exactly neutral by the cautious addition of acetic acid; there was produced a beautiful purple precipitate, which dried at 212° , gave the following results, from which the formula $C_{18}H_{10}NO_5 + 3PbO$ may be deduced.

0.531 of substance gave 0.409 of carbonic acid, and 0.106 of water.

0.354 gave 0.162 of oxide of lead, and 0.067 of metallic lead.

The numerical results are hence

	Theory.		Experiment.
18 Carbon . . .	109.8	21.58	21.29
10 Hydrogen . .	10.0	1.97	2.21
1 Nitrogen . . .	14.1		
5 Oxygen . . .	40.0	10.63	10.37
3 Oxide of lead .	334.8	65.82	66.13
	508.7	100.00	100.00

B. Analysis of Betaorceine.

The betaorceine was, previous to analysis, dried in LIEBIG's apparatus at a temperature of 212° .

A. 0.201 gramme of material gave 0.402 of carbonic acid, and 0.097 of water.

B. 0.248 gramme of same substance gave 0.493 of carbonic acid, and 0.113 of water.

C. 0.381 gramme of a different specimen gave 0.752 of carbonic acid, and 0.169 of water.

These results give in 100 parts

	A.	B.	C.
Carbon	55.30	54.97	54.58
Hydrogen	5.35	5.07	4.92
Oxygen and Azote .	39.35	39.96	40.50
	100.00	100.00	100.00

In the last analysis it would appear that a small quantity, 1 per cent., of the substance had been lost.

The formula deduced from these numbers being the same with that adopted for orceine by LIEBIG, $C_{18}H_{10}NO_8$ gives the result :

18 Carbon . .	= 109·8	55·45
10 Hydrogen . .	= 10·0	5·05
1 Nitrogen . .	= 14·1	39·50
8 Oxygen . .	= 64·0	
	197·9	100·00

differing from alphaorceine in containing three equivalents more of oxygen.

To determine the constitution of betaorceine in its salts, an ammoniacal solution of betaorceine was mixed with a solution of acetate of lead, and the liquor having been rendered neutral by the addition of acetic acid, the fine purple precipitate which formed was collected, and having been washed until all excess of lead had been completely removed, it was dried in a stove, the temperature of which did not exceed 150° FAHR. It still, however, contained combined water, and in order to obtain it anhydrous, it was dried in LIEBIG's apparatus at 212°, after which it did not part with any more water, although oil at 280° was used as the source of heat. 1·600 gramme dried in this way gave 1·377 of dry substance, hence it contained 13·94 per cent. of combined water. In the anhydrous state it was analysed.

A. 1·111 gramme gave 0·313 of oxide of lead, and 0·345 of metallic lead.

0·710 gramme of the same substance gave 0·526 of carbonic acid, and 0·131 of water.

B. 0·642 of another quantity prepared at a different time, and dried in an oil bath at 250° FAHR. gave 0·443 of carbonic acid, and 0·105 of water.

0·314 of the same substance gave 0·198 gramme of oxide of lead.

The formula $C_{18}H_{10}NO_8 + 3 PbO$ expresses very accurately the results so obtained; the numbers in 100 are

	Theory.	Experiment A.	Experiment B.
18 Carbon . .	= 109·8	20·62	19·35
10 Hydrogen . .	= 10·0	1·88	1·82
1 Nitrogen . .	= 14·1	16·19	15·78
8 Oxygen . .	= 64·0		
3 Oxide of lead =	334·8	61·39	63·05
	532·7	100·00	100·00

This compound, as dried, when first precipitated at 150° appears to have retained nine equivalents of water, which would give 13·2 gramme per cent.; the quantity obtained having been 13·97.

A compound of betaorceine with oxide of copper was prepared with the same precautions, which were made use of in the cases already described. It was then dried

in a stove until it ceased to lose weight. It was of a very rich purple-brown colour. Its analysis took place as follows:

1.113 grammes dried in LIEBIG's apparatus at a temperature of 212° , gave 0.997 of dry substance, indicating the presence of 10.6 water in 100 parts.

0.721 grammes of the hydrated substance, ignited until all organic matter was completely burned out, the resulting mixture of oxide and metallic copper moistened with nitric acid and again ignited, gave 0.209 grammes of oxide of copper, corresponding to 29.0 per cent. for the hydrated, and to 32.37 per cent. for the dried substance.

0.709 grammes of the dried substance gave 0.787 of carbonic acid, and 0.250 of water.

These results indicate the formula $C_{18}H_{14}NO_{12} + 3CuO$ for the substance dried at 212° , giving

	Theory.		Experiment.
18 Carbon	= 109.8	31.14	30.68
14 Hydrogen. . . .	= 14.0	3.96	3.92
1 Nitrogen	= 14.1	31.22	33.03
12 Oxygen	= 96.0		
3 Oxide of copper. =	118.8	33.68	32.37
	352.7	100.00	100.00

In this form the substance contained therefore still four atoms of water, the formula being really $C_{18}H_{10}NO_8 + 3CuO + 4HO$; and as dried at 150° , it appears to have contained four more, which should give 9.3 per cent., or five more, which should give 11.3 per cent. of hydrate water, the experimental result being 10.6. I consider it most likely that in the fresh precipitated form this compound is expressed by $C_{18}H_{10}NO_8 + 3CuO + 9HO$.

It may, therefore, be now considered as definitely fixed that the betaorceine is identical with the orceine discovered by ROBIGNET and analysed by DUMAS; and that the formula $C_{18}H_{10}NO_8$, proposed by LIEBIG, truly expresses its constitution.

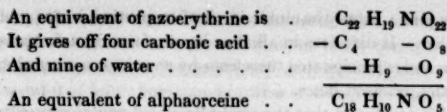
In the analysis of orceine DUMAS obtained 55.9 per cent. of carbon, whilst the formula he adopted, $C_{16}H_9O_7N$, required only 55.3. I would refer this to the presence of some alphaorceine, for indeed his results express the constitution of the mixtures of the two orceines which exist very generally in archil. In analysing mixed orceine the carbon generally falls between 56 and 57 per cent., and several times came out almost precisely what DUMAS obtained; but considering the almost constant co-existence of alphaorceine, it is certain that the lowest value obtained in good analyses is that which assigns its true proportion. It is much rarer to find the carbon approximating to the quantity contained in alphaorceine, and I met with pure alphaorceine only once out of the great number of specimens of archil I examined. DUMAS supposed his formula to be confirmed by the analysis of the silver salt, which contained 58.6 of oxide of silver, whilst theory required 58; the true formula of a bi-basic salt giving the quantity of oxide of silver 54.0 per cent. I consider the differ-

ence here to have arisen from admixture of a still more basic salt, produced by the presence of a slight excess of ammonia in the solution of orceine. Indeed, by boiling the solution of orceine in ammonia, the excess of ammonia cannot be completely driven off, so as to leave any kind of neutral compound; and to form salts of definite constitution I found it indispensable to add small quantities of acid to the mixed liquors, so as to leave the supernatant liquor exactly neutral. If the acid be in excess the precipitate becomes contaminated by some orceine which separates along with it. The washing of these salts of orceine must be continued until the filtered liquors become tinged crimson, owing to a certain quantity of the orceine salt itself being dissolved, which does not happen until the removal of the foreign saline matter has been nearly perfect.

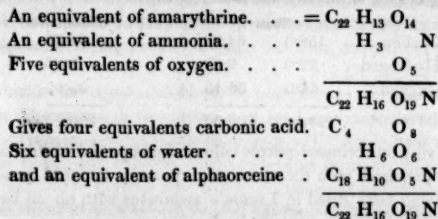
In order to ascertain the constitution of the violet compound of ammonia and of orceine, 0.273 of betaorceine was kept in a current of dry ammonia as long as any increase of weight took place. The combination was accompanied with the evolution of heat, and the violet-coloured substance which resulted was found to weigh 0.295 gramme. On exposure to a temperature of 212° in a current of air, the ammonia was after some time totally removed, and the betaorceine remained unaltered. This proportion of ammonia corresponds to 8.06, absorbed by 100 of betaorceine, very closely approximating to 8.58, which theory gives equivalent to an atom. The violet compound is therefore to be considered as $C_{18}H_{10}NO_8 + NH_3$; and I have found that the betaorceine when dried at 150° FAHR. retains an equivalent of water, which it loses at 212° , and that consequently the bodies $C_{18}H_{10}NO_8 + AdH$ and $C_{18}H_{10}NO_8 + OH$ are equivalent to one another. This hydrate of betaorceine is of a much lighter colour than the anhydrous compound, and it will be hereafter shown that a corresponding body, $C_{18}H_{10}NO_8 + SH$, is capable of being formed.

The most important question in the philosophical history of these bodies, that of their origin, requires now to be discussed, and as there is but little doubt that the betaorceine, $C_{18}H_{10}NO_8$, is formed by the gradual oxidation of the alphaorceine, $C_{18}H_{10}NO_5$, our views need only involve the production of the latter compound. In the case of archil prepared from the *Variolaria dealbata*, where the primitive substance is orceine, the production of orceine is easily understood; the dry orceine having the constitution $C_{18}H_7O_3$, it requires only the combination of an atom of ammonia and the absorption of two or five equivalents of oxygen to form the one or the other variety of orceine. But in the case of ordinary archil, where the *Parmelia* or the *Rocella* had been used, the transition from the erythrine series to that of orceine becomes much more complex, as not only a certain quantity of hydrogen, but also four equivalents of carbon must be removed; the substances of the former group containing twenty-two atoms of that element, while those of the latter include only eighteen.

The azoerythrine is probably the substance which forms the transition between the two groups, and from it the origin of alphaorceine can easily be explained.

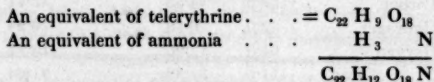


From the very small quantity of azoerythrine which I could find present in archil, at any one moment, it is probably decomposed as fast as formed, very nearly, and either orceine may be considered as arising directly from amarythrine as follows :

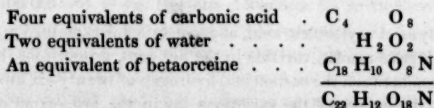


It is, however, most likely that the amarythrine is all changed into azoerythrine before forming orceine, and hence that azoerythrine has the formula $C_{22} H_{16} N O_{19}$, the three equivalents of water I found being probably in a form capable of elimination.

It is also possible that from telerythrine the betaorceine may be at once formed. Thus



should give



I do not think it probable that this reaction ever occurs in the actual manufacture of archil. In contact with air and ammonia, the erythryline can scarcely advance beyond the condition of amarythrine, and from it the azoerythrine being produced by the direct combination of the ammonia, the alphaorceine is ultimately formed.

III. Of Erythrolic Acid.

This is the crimson substance, distinguished by its semifluid consistence at ordinary temperatures, and its solubility in ether, which is obtained by treating the solid extract of archil by warm sulphuric ether, as already described. It possesses no other property remarkably characteristic. It is almost insoluble in water, which,

however, it tinges pink : totally insoluble in oil of turpentine, but abundantly soluble in alcohol and ether. It dissolves in alkaline liquor, forming a fine purple (crimson) coloured solution, and is precipitated therefrom by an acid or a neutral salt. It forms, with metallic oxides, crimson lakes.

By careful trial it was found that the erythroleic acid contains no nitrogen.

0.318 gramme gave on analysis 0.744 gramme of carbonic acid, and 0.267 of water.

The formula $C_{26}H_{22}O_8$ is thereby indicated, giving

	Theory.		Experiment.
26 Carbon . .	158.6	64.84	64.70
22 Hydrogen . .	22.0	9.00	9.33
8 Oxygen . .	64.0	26.16	25.97
	244.6	100.00	100.00

A quantity of a very fine crimson-purple coloured compound of this substance with oxide of lead was prepared with the remaining quantity which I possessed of this substance, and having been dried in LIEBIG's apparatus with an oil bath at 250° , it was analysed.

0.578 gramme of material gave 0.913 of carbonic acid, and 0.325 of water.

0.255 gramme of material gave 0.061 of metallic lead, and 0.015 of oxide of lead.

The resulting formula is $C_{26}H_{22}O_8 + PbO$, giving

	Theory.		Experiment.
26 Carbon . . .	158.6	44.53	43.41
22 Hydrogen . . .	22.0	6.18	6.24
8 Oxygen . . .	64.0	17.96	18.71
1 Oxide of lead . .	111.6	31.33	31.64
	356.2	100.00	100.00

Besides the analysis of erythroleic acid, above detailed, I examined a great number of specimens which gave results, variable in the per cent. proportions, but indicating the constant relation between the carbon and hydrogen of twenty-six atoms to twenty-two atoms, whilst the source of the variations lay in the proportion of oxygen not being constant. The per cent. proportion of carbon was generally higher, and that of oxygen as much lower than the numbers given by the analysis which has been brought forward, which indeed I selected as showing the maximum of oxygen, which I found this crimson substance soluble in ether to contain. This inconstancy in the constitution of erythroleic acid, arises from the occasional presence of another substance, also crimson, semifluid, and soluble in ether, which I term erythroleine, and which I shall describe in detail hereafter. These two bodies are related to each other nearly as the two orceines, and like them are distinguishable only by analysis.

In order to trace the origin of this remarkable substance, which from the minute quantity in which it exists is evidently a collateral product, it is necessary to recur to

the examination of the archil weed. Besides the erythryline, which is the origin and basis of the archil series, I noticed the existence in small quantity of the roccellic acid of HEEREN, which, however, I found in so small quantity that I could not institute any analyses of it or of its compounds. It was looked upon by HEEREN as being distinct from the bodies which produce colour, and so far as the proper orceine (lichen-red) is concerned, with perfect justice, but when we consider its constitution there can be little doubt of its being the source of erythrolic acid. We possess an analysis of it by LIEBIG, made with a portion sent to him by HEEREN, and certainly the highest confidence may be reposed in his result. The formula $C_{16}H_{16}O_4$ was adopted by LIEBIG, and his numbers are

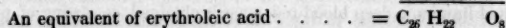
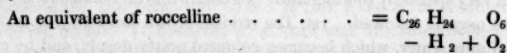
	Theory.	Experiment.
Carbon	67.05	67.94
Hydrogen . . .	10.95	10.76
Oxygen	22.00	21.30
	100.00	100.00

LIEBIG remarks that the formula $C_{17}H_{17}O_4$ agrees still better with his results, but he prefers the simpler 4 (C_4H_4O). A formula, however, which requires less carbon and more hydrogen than was obtained in the analysis of a pure substance cannot be adopted, and this objection applies to $C_{17}H_{17}O_4$ also, though not in so great a degree. The only support indeed which this formula receives is from an experiment made by HEEREN, who found that the roccellate of lime contained 15.9 of lime per cent., the oxygen of which is one fourth that of the roccellic acid. On this isolated result I do not consider that much stress can be laid; and as this roccellic acid, or as I propose to term it, roccelline, is the only constituent of lichen possessing hydrogen enough to allow of the formation of erythrolic acid, I would suggest to chemists the probability of its formula being rather $C_{26}H_{24}O_6$, from which are obtained the numbers.

	Theory.	Experiment.
26 Carbon . = 158.6	68.78	67.94
24 Hydrogen . 24.0	10.40	10.76
6 Oxygen . . 48.0	20.82	21.30
	230.6 100.00	100.00

A sesquisalt of this acid ($C_{26}H_{24}O_6$) + $\frac{1}{2}$ Ca O should give 15.6 of lime, and was perhaps that analysed by HEEREN.

The proposed formula being assumed, it is very easy to show how from it erythrolic acid may be formed.



MDCCCL.

2 q

The characteristic constituents of archil, viz.

1. Azoerythrine.
2. Alphaorceine.
3. Betaorceine.
4. Erythroleic acid.

having been now described, and the decompositions by which they originated having been reduced to laws, I shall proceed to the next portion of my subject, the constitution of ordinary litmus.

Section III. *Of Litmus.*

In order to obtain in an isolated form the constituents of litmus, the following method was had recourse to.

The cubical masses of commercial litmus having been reduced to a fine powder, are first treated with boiling water as long as the solution comes away much coloured. The mass of insoluble matter which remains, and which is of a paler blue than the original substance, is to be then diffused through water so as to form a thin cream, and muriatic acid added until all effervescence has ceased, and the thick opaque brick-red liquor reacts very acid. The whole is to be thrown upon a filter, and the red substance which remains is to be washed with water until all excess of muriatic acid has been removed, and is then to be carefully desiccated.

When completely dry, this mass is to be boiled in successive portions of alcohol, until every thing soluble in that fluid shall have been taken up. The deep red alcoholic liquors are to be then distilled in a water-bath to dryness, and the resulting solid material digested in warm sulphuric ether until it no longer becomes coloured. The ethereal solutions thus obtained, yield on distillation in a water-bath a fine crimson oily material, which is nearly fluid. To obtain this free from some of the other substances which the larger quantity of ether might have taken up, it may be redissolved in a small quantity of ether, and the solution after standing for some hours, decanted from any trace of insoluble matter, and evaporated to expel all the ether, for which purpose exposure for some time to a temperature above 212° is requisite. To the substance thus obtained I give the name of Erythrolein.

The substance from which the erythrolein has thus been removed, and which is distinguished by its solubility in alcohol, must be dried in a current of air at a temperature of 212° to expel all residual traces of ether, and may then be considered pure. To it I give the name of Erythrolitmine.

The brownish red mass which resisted the action of the alcohol, yields its colouring material but very sparingly to water also. To obtain it in an isolated form, one or other of two plans may be followed. 1st, The reddish brown mass may be boiled in large quantities of pure water, which becomes coloured pretty deeply, and by evaporating these reunited liquors, a deep blood-red mass is obtained, consisting of pure colour-

ing material; or 2nd, the reddish brown mass may be boiled in water of ammonia, in which it dissolves, giving a blue solution. When this is evaporated to dryness, the greater part of the ammonia separates, and to remove the last traces, the residual mass may be moistened with dilute muriatic acid, and then washed with alcohol until the excess of acid and the sal-ammoniac have been removed. To this substance I give the name of Azolitmine.

The blue liquors which are obtained in the first place, by digesting the litmus cakes in boiling water, contain but a very small quantity of colouring matter, in comparison to what might be expected from the great depth of colour they present. To obtain this colouring matter in a pure condition, a solution of acetate of lead is to be added, and the purple precipitate which falls, having been well washed, is to be treated while still moist with a current of sulphuretted hydrogen, until completely decomposed. The resulting compound of the colouring matter with the sulphuret of lead is to be very well washed to remove all excess of sulphuretted hydrogen, and then digested in warm water of ammonia: a deep blue liquor is obtained, which is to be evaporated to dryness, and then moistened with muriatic acid and washed with warm alcohol to remove the sal-ammoniac which is formed. The colouring material remains as a deep brown-red powder.

In most cases this substance will be found to be azolitmine nearly pure, but I have met it totally free from azote, and to constitute a peculiar substance, resembling azolitmine in properties, but remarkably distinct from it in constitution. This substance is very rare in litmus. It constitutes but a very unimportant portion of the colouring substance, and hence I propose, for the adoption of chemists, the name Spaniolitmine, to distinguish it from the constant constituents already noticed, the Greek word *σπανιος* signifying rare.

The colouring constituents of litmus are therefore in their natural condition red, and the blue of litmus is produced by combination with a base. There are, properly speaking, only two characteristic colouring matters in litmus, the erythrolitmine and the azolitmine. For the erythrolein is coloured crimson purple only by alkalies, and the spaniolitmine occurs but very seldom. In the litmus of commerce these colouring substances are combined with lime, potash, and ammonia, and there is mixed up in the mass a considerable quantity of chalk and sand.

I shall now proceed to the detailed account of the constitution and properties of these various substances.

I. Of *Erythrolein*.

This substance, as obtained by evaporating the ethereal solutions, is semifluid at ordinary temperature, and completely liquid at 100° FAHR. Its solution in ether is of a very fine red colour. It dissolves in alcohol with the same colour, and tinges water pink, without however dissolving in any very sensible proportion. It is insoluble in oil of turpentine, and dissolves in water of ammonia, with a magnificent

purple colour, without any trace of blue. It is not volatile, and yields, when heated strongly, the usual products of decomposition of substances which contain no azote, from which substance its analysis shows it to be completely free. With metallic salts it generates fine purple lakes by double decomposition. It will be at once seen that in all these properties it identifies itself with the substance detected in archil termed erythroleic acid; it is, however, more easily fusible, and, as will be now seen, differs in constitution.

The analysis of many specimens of this substance, prepared at different times, and with different parcels of litmus, furnished results somewhat discordant as to the quantity of oxygen, which they indicated this substance to contain, but giving constantly the same relation between the carbon and the hydrogen, as has been already shown to exist in the erythroleic acid; and I ultimately met with a quantity of this substance, which I consider to have been pure, and which although small, yet gave a result so definite and characteristic, that I shall detail it as expressing the true constitution of this remarkable body. It furnished the largest amount of carbon I obtained in any instance.

0.283 gramme of material gave 0.760 of carbonic acid, and 0.272 of water.

These numbers indicate the formula $C_{26}H_{22}O_8$, by which the results are as follows:

	Theory.		Experiment.
26 Carbon .	158.6	74.43	74.27
22 Hydrogen	22.0	10.33	10.68
4 Oxygen .	32.0	15.24	15.05
	212.6	100.00	100.00

In order to test this formula by the analysis of the compound of erythrolein with oxide of lead, I prepared a portion of it by precipitating the solution of erythrolein in ammonia, by means of a solution of acetate of lead. The fine purple lake which was produced was dried at 212° in LIEBIG's apparatus, and then analysed. The result did not give any simple relation between the oxide of lead and the equivalent of erythrolein, owing probably to the accidental omission of the precautions I have already noticed as being necessary in preparing salts of this kind, but the organic matter had exactly the same composition as was given in the first experiment; there did not appear to have been any replacement of water.

The formula of erythroleic acid being $C_{26}H_{22}O_8$, it will be at once seen that the erythrolein contains half as much oxygen to the same hydrogen and carbon. Indeed, I consider the fluctuations in the results of my analyses of erythrolein and erythroleic acid, which for a long time gave me great trouble and embarrassment, to be caused by their simultaneous presence as products of the same chain of reaction. In archil the erythroleic acid appears to preponderate, as the mixed erythrolein from archil seldom gives above 67 per cent. of carbon, whilst in litmus the erythrolein, when analysed, seldom gives a value for carbon below 70 per cent., and generally 72

or 73. The total quantity of these substances is, however, very small, and it is necessary to operate upon at least a pound of commercial litmus to obtain twelve or fifteen grains of erythrolitmin.

Regarding the origin of this substance, I shall make no remark until the substance next in order has been described.

II. Of Erythrolitmine.

This substance, which from its composition and the quantity in which it exists, constitutes one of the most important ingredients in litmus, is to be obtained in the manner described under the head of the general analysis of litmus. By exposure to a temperature of 230° FAHR. for an hour or two, it may be completely freed from all chance of contamination by adhering ether.

It is of a beautiful and pure bright red colour, without any tinge of crimson. It is sparingly soluble in water, which it colours red: very sparingly soluble also in ether, which it scarcely tinges, but abundantly soluble in alcohol, forming a fine deep red liquor, which if saturated when boiling, deposits on cooling a considerable quantity of erythrolitmine under the form of small soft granular crystals, which are not at all brilliant, though of a fine deep red colour. This is the only colouring substance in all this series, in which I have been able to detect the slightest disposition to crystallize.

In a pretty strong solution of potash the erythrolitmine dissolves, giving a blue liquor. With ammonia it combines, forming a blue substance, which has the singular character of being totally insoluble in water. Although the erythrolitmine is itself very sparingly soluble in water, yet if water tinged by means of it be mixed with some water of ammonia, the blue compound gradually subsides, or may be removed by filtration, leaving the liquor absolutely colourless. The separation of this erythrolitmine-ammonia may be accelerated by boiling. This blue compound is, however, very instable; it cannot be dried without losing ammonia and becoming reddish purple. In this state it still retains a portion of the ammonia very firmly, so that it cannot be separated by means of heat. The erythrolitmine combines with metallic oxides, and forms lakes of a very fine purple colour; their preparation, however, requires precautions, to which I shall hereafter direct attention.

The erythrolitmine dried at 212°, gave on analysis the following results, with separate specimens.

A. 0.422 gramme of material gave 0.853 of carbonic acid, and 0.330 of water.

B. 0.423 gramme of material dried at 250°, gave 0.844 of carbonic acid, and 0.311 of water. The composition indicated by these results is

	Theory.		A.	B.
26 Carbon	= 158.6	55.53	55.78	55.3
23 Hydrogen	= 23.0	8.05	8.69	8.1
13 Oxygen	= 104.0	36.42	35.43	36.6
	285.6	100.00	100.00	100.0

The second quantity of substance was dried at 250° in order to determine whether the twenty-third atom of hydrogen arose from accidentally-present water. It is evident, consequently, that the true formula of the erythrolitmine is $C_{26}H_{22}O_{12} + Aq$. When the substance has been dried below 212° , it retains, though loosely, another equivalent of water, which corresponds to almost exactly three per cent. It is then $C_{26}H_{22}O_{12} + 2 Aq$.

If dry ammonia be passed over erythrolitmine, it is absorbed with the production of considerable heat, and if the substance containing 2 Aq be employed, the second equivalent of water is expelled. The resulting mass is deep blue. When this mass is heated to 212° , it loses the blue colour and a portion of ammonia is expelled, a dark reddish purple mass remaining, from which, however, all ammonia cannot be expelled. The action is therefore the same with the dry gas as with ammonia dissolved in water.

This description is substantiated by the following experiments.

0.709 of the bihydrated substance, $C_{26}H_{24}O_{14}$, was exposed to a stream of dry ammonia until all the water, which at first separated, had been removed by the excess of gas, and the substance had become quite dry and cold. It then weighed 0.729. It was then heated in a current of air to 250° FAHR. until it ceased to lose weight, when it weighed 0.687 gramme. Theory indicates the following result.

$C_{26}H_{22}O_{12} = 276.6$	Substance = 276.6	Substance = 276.6
$2 H O = 18.0$	give $H O = 9.0$	and then $\frac{N H_3}{2} = 8.5$
294.6	$N H_3 = 17.1$	
	302.7	285.1
Now 709 : 729 :: 294.6 : 302.8		
and 709 : 687 :: 294.6 : 285.5		

If the erythrolitmine had given off all ammonia but retained an equivalent of water, the numerical result would have been the same, but the properties of the purple-brown substance show that it is a definite compound. It is quite insoluble in spirit, and when treated by a dilute acid, immediately assumes the bright red colour of pure erythrolitmine. In order further to test its constitution it was analysed.

0.347 gramme of substance gave 0.691 of carbonic acid, and 0.265 of water.

Hence the formula $C_{26}H_{22}O_{12} + \frac{N H_3}{2}$, which gives

	Theory.	Experiment.
26 Carbon = 158.6	55.63	55.07
23.5 Hydrogen = 23.5	8.24	8.48
12 Oxygen = 96.0	36.13	36.45
$\frac{1}{2}$ Nitrogen = 7.0		
	285.1	100.00
	100.00	100.00

The erythrolitmine-ammonia being insoluble, the compounds of erythrolitmine with metallic oxides cannot be formed by the method of double decomposition used in so many other cases. The mode I found most convenient, was to boil the erythrolitmine with some alcohol, so as to have it partly dissolved and partly diffused in minute division through the liquor, and then to add it to a solution of basic acetate of lead. A deep purple precipitate forms, which is to be boiled for a few minutes, then well washed and filtered. Having been dried at 212° in LIEBIG's apparatus, it was analysed.

0.532 gramme gave 0.606 of carbonic acid, and 0.229 of water.

0.583 gave 0.146 of oxide of lead, and 0.105 of metallic lead.

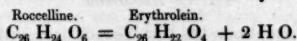
The composition resulting from these numbers indicates the formula $C_{26}H_{22}O_{12} + 2 Pb O$, which gives

	Theory.		Experiment.
26 Carbon . .	158.6	31.73	31.52
22 Hydrogen . .	22.0	4.40	4.78
12 Oxygen . .	96.0	19.21	19.27
Oxide of lead	223.2	44.66	44.43
	499.8	100.00	100.00

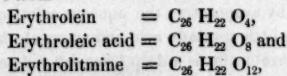
The twenty-third equivalent of hydrogen is here eliminated and replaced by oxide of lead, the true formula of the erythrolitmine is therefore $C_{26}H_{22}O_{12}$.

It is evident that this substance belongs to the same series of bodies as the erythrolein and the erythroleic acid, the relation of the carbon and hydrogen being the same, the oxygen, however, having increased to twelve equivalents. That this body is a direct product of the oxidation of erythroleic acid, is completely shown by the fact, that if semifluid erythroleic acid be left exposed to the air for some weeks, it gradually solidifies; it is then insoluble in ether, is coloured blue by ammonia, and is, in fact, found to have been changed into erythrolitmine. The bodies are therefore related to each other as the two orceines.

The origin of erythrolein is a point on which, however, I do not at all feel perfectly decided. It will be recollected how beautifully simple the production of erythroleic acid from roccelline appeared to be, two equivalents of hydrogen being replaced by two of oxygen. The production of erythrolein does not appear to me by any means so easily explained. The relation between roccelline and erythrolein is extremely simple.

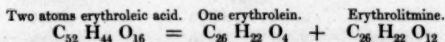


And if we looked no further, it might easily be said that by a metameric change the roccelline, in decomposing, yielded erythrolein and water, and that afterwards the absorption of oxygen gave from



a chain of reactions among the simplest possible.

If this were so, we should, however, find erythrolein existing principally among the earliest products of the general breaking up of the colourless substances in the lichen, and erythroleic acid should co-exist in quantity with erythrolitmine among the latter results of gradual oxidation. This, however, is not the case. In archil, the earliest stage, there is but a mere trace of erythrolein and of erythrolitmine, but abundance (comparatively speaking) of erythroleic acid, whilst in the litmus, where the train of decompositions is much more advanced, scarcely a trace of erythroleic acid can be found, but the erythrolein makes its appearance in greater quantity, and a great portion of the colouring matter of the litmus is erythrolitmine. I am hence induced to consider these substances as formed in the following order. By the reaction already described, the roccelline is converted into erythroleic acid, which then breaks up into erythrolein and erythrolitmine, as it can be seen that



The erythrolein, I consider, may then absorb oxygen and form erythroleic acid, which will be again broken up and ultimately all converted into the final term erythrolitmine. In the commencement, therefore, the erythroleic acid is tolerably permanent until the roccelline is all exhausted; and indeed its permanency is promoted by the fact that in making archil too rapid an oxidation might do much harm, the alphaorceine being a richer colour than the betaorceine. But in making litmus it is decomposed, and whilst the great mass rapidly forms erythrolitmine, small quantities of erythrolein appear to escape the action of the air.

Finally, to sum up the results of this part of the investigation, I look upon these three bodies as all derived from roccelline; but notwithstanding the beautiful simplicity of their formulæ, which would appear to indicate them to be all oxides of one compound radical, which contained $\text{C}_{26} \text{H}_{22}$, I look upon them as, when once formed, being quite independant of each other: thus, if erythrolitmine was erythrolein + eight oxygen, we should be able, by deoxidizing means, to change erythrolitmine into erythrolein; this cannot be done, and hence, as will be shown more fully when describing the results of decolorization of these bodies, I look upon each as having an internal constitution distinct from either of the others.

III. Of Azolitmine.

The preparation of the azolitmine has been already described: it constitutes almost pure, the substance separated by means of muriatic acid, and insoluble in alcohol. It is sparingly soluble in water, and still more soluble in water of potash or of ammonia, with which it forms the peculiar blue of litmus, and may be obtained, as already noticed, either by evaporating the aqueous solution, or by treating the ammonia compound with a little muriatic acid and warm alcohol.

As thus prepared the azolitmine is a deep brownish-red powder, totally destitute of crystalline texture. Its general characters of solubility, &c. are indicated by the

mode by which it is prepared, and it is distinguished by being coloured pure blue by the alkalis, and by containing nitrogen as a constituent.

Its analysis was effected as follows: the determination of the azote was effected by the same method of relative volumes of the carbonic acid and nitrogen gases employed in the other instances. The best precautions were taken to ensure success, and the results, though not so uniform as in other instances, owing probably to some irregularity in the combustion, gave a proportion almost exactly eighteen carbon to one of azote. The detail of numbers follows:

No. of Tube.	CO ₂ + N.	N.	CO ₂ .	N : CO ₂ .
A.	128	7	121	∴ 1 : 17·3
B.	318	17	301	∴ 1 : 18·3
C.	196	11	185	∴ 1 : 16·8
D.	528	28	500	∴ 1 : 17·8

The mean result is 1 : 17·6, nearly 1 : 18, which number I therefore adopt. The relation of carbon to azote is thus the same as in orceine.

A. 0·307 of substance dried at 212° gave 0·550 of carbonic acid, and 0·148 of water.

B. 0·376 gramme of another quantity, dried also at 212°, gave 0·683 carbonic acid, and 0·187 of water. Hence in 100 parts

	A.	B.
Carbon	49·50	50·05
Hydrogen	5·35	5·52
Oxygen and azote	45·15	44·43
	100·00	100·00

The carbon being to the azote as 18 : 1, there are two formulæ which express nearly the results of the analyses just described, though the accordance is not satisfactory with either formula. These formulæ are C₁₈ H₁₁ O₁₁ N, and C₁₈ H₁₀ O₁₀ N, giving

18 Carbon	109·8	49·3	18 Carbon	109·8	51·3
11 Hydrogen	11·0	4·9	10 Hydrogen	10·0	4·7
11 Oxygen	88·0	45·8	10 Oxygen	80·0	44·0
1 Nitrogen	14·1		1 Azote	14·1	
	222·9	100·0		213·9	100·0

Considering the deviation of the analytical result from the numbers assigned by either formula to have arisen from imperfect desiccation, I had another portion dried carefully at 230° until no more traces of water were given off, and then it was analysed.

0·432 gramme gave 0·783 of carbonic acid, and 0·200 of water. Hence per cent.

Carbon	49·94	} 100·00
Hydrogen	5·14	
Oxygen and nitrogen	44·92	

almost identical with the former results, and indicating either the formula to be $C_{36}H_{21}N_2O_{21}$, or that this substance retains half an equivalent of water very powerfully, and the formula becomes $C_{18}H_{10}NO_{10} + \frac{1}{2}Aq$, by which the numbers are given:

18 Carbon	50.27	} 100.00	109.8	} 218.4
10.5 Hydrogen	4.81		10.5	
10.5 Oxygen and nitrogen	44.92		98.1	

I was anxious to examine the compound of this body with ammonia, but found that it gave results much less definite than those obtained with the erythrolitmine and the orceine. If the blue ammoniacal liquor be evaporated to dryness, the ammonia is expelled for the most part along with the last portion of water, but the quantity which remains behind is not constant. The absorption of dry ammonia was found also to be too irregular to be made the basis of numerical results.

The ammoniacal solution of azolitmine gives with metallic solutions precipitates which are either purple or blue, according to the proportion of metallic oxide which they contain. Using the precautions already so often described, the combinations of azolitmine with metallic oxides are produced, containing the smallest possible proportion of base, and of a fine purple. In this way the specimens were prepared, the analyses of which will now be detailed.

The *azolitmate of lead*, although of a beautiful purple when freshly prepared, loses that tint when dried with LIEBIG'S apparatus in an oil bath, and becomes blue. Of a specimen dried at 250° FAHR. 1.226 gramme gave 0.512 of oxide of lead, and 0.218 of metallic lead.

1.188 gramme of the same substance gave 0.832 of carbonic acid, and 0.220 of water.

From this results the formula $C_{18}H_{10}NO_{10} + 3PbO$, giving

	Theory.		Experiment.
18 Carbon	= 109.8	20.01	19.35
10 Hydrogen	= 10.0	1.82	2.00
1 Nitrogen	= 14.1	} 17.15	19.27
10 Oxygen	= 80.0		
3 Oxide of lead	= 334.8	61.02	59.38
	548.7	100.00	100.00

The salt or lake formed with protoxide of tin in the cold is of a beautiful purple colour. It gave the following result.

0.611 gramme of material gave 0.466 of carbonic acid, and 0.156 of water.

1.328 of material gave, by ignition until all organic matter was burned out, then moistening with nitric acid and subsequent ignition a second time, 0.777 of oxide of tin (peroxide) quite white.

The formula $C_{18}H_{10}NO_{10} + 4SnO + 2Aq$, gives

	Theory.		Experiment.
18 Carbon . . .	109.8	22.01	21.10
12 Hydrogen . .	12.0	2.41	2.84
1 Nitrogen . . .	14.1	28.48	30.07
16 Oxygen . . .	128.0		
4 Tin.	235.6	47.10	45.99
	499.5	100.00	100.00

If a temperature be applied to this salt sufficiently high to expel the water, it becomes partly decomposed, and was hence analysed only in this hydrated condition. If when in this state it is boiled with water it becomes completely decolorized, and the tin is changed into the form of peroxide, a grayish white compound is produced, which rapidly absorbs oxygen, and generates, thereby, a red compound of regenerated azolitmine with peroxide of tin. The exact nature of the reaction to which this effect is due, will be examined in detail hereafter.

This azolitmine, which is the only constituent of litmus containing azote, appears by the analytical results just given to be connected in a most simple and remarkable manner with the principles of archil, alphaorceine and betaorceine. In fact, the proportion of carbon, of hydrogen, and of azote being the same in these bodies, they differ only in the quantity of oxygen they contain, their formulæ being

Alphaorceine . . .	$C_{18}H_{10}NO_5$.
Betaorceine	$C_{18}H_{10}NO_8$.
Azolitmine	$C_{18}H_{10}NO_{10}$.

As in this portion of the paper I wish to confine myself to experimental results, I shall not enter now into any consideration of their theoretical nature, further than to notice, that as in the series of erythrolein and erythrolitmine, although these bodies are simply produced by the continued action of oxygen, yet when once formed they cannot be looked upon as oxides of the same compound radical, but are substances totally independent of each other.

IV. Of Spaniolitmine.

In the majority of cases, the salt of lead prepared from the solution of litmus in water contains only azolitmine, but in some, I recognized the presence of the substance noticed under the name of spaniolitmine in the description of the analysis of litmus, and which is distinguished from azolitmine by not containing nitrogen. The existence of this substance rendered useless a great mass of results which I had obtained in the commencement of my investigations; the substances employed having been mixtures in variable proportions of the two bodies, and having consequently given analytical expressions for the soluble colouring matter of litmus, different in each experiment. The source of this was at last traced to the presence of spaniolitmine, which, when once mixed with azolitmine, cannot be separated from it by any method

that I know of, and consequently it is not until all the labour of preparation and analysis has been gone through, that any opinion can be formed as to which substance, or what mixture of the two substances, was present. The simplest analytical means consist in collecting the mixed gases produced by the combustion of the specimen, and determining the relation by volume between the carbonic acid and the azote: if it be 18:1, the substance is pure azolitmine; if there be no azote, it is pure spaniolitmine, which occurs but very seldom; and, if, as is generally the case, the proportion is thirty, forty, or fifty to one, the substance is a mixture on which it is useless further to experiment. So rare is the presence of this body in a form, even nearly pure, that out of more than forty trials I obtained it in a state to justify its being made the object of quantitative investigation only twice. In one of these the absence of azote was complete, in the other a small quantity of azote remained, being 1 to 200 of carbonic acid, a proportion so small that it could not interfere with the analytical results.

The spaniolitmine resembles azolitmine and erythrolitmine, in being turned blue by alkalis. It is of a bright red colour, insoluble in alcohol and in ether, and very sparingly soluble in water, which it tinges bright red. In this respect it differs somewhat from the azolitmine, which is more soluble in water, and colours the water a darker and browner red. Its compound with ammonia is decomposed by a very moderate heat, although imperfectly, like the other bodies already noticed. Its precipitates with metallic solutions are identical in appearance with those formed by the azolitmine.

The analysis of this substance was as follows:

0·311 gramme of spaniolitmine dried in LIEBIG's apparatus with an oil bath at 250° FAHR., gave 0·501 of carbonic acid, and 0·087 of water.

Hence results the formula $C_{18}H_7O_{16}$, giving

	Theory.		Experiment.
18 Carbon . . .	109·8	44·85	44·54
7 Hydrogen . . .	7·0	2·86	3·11
16 Oxygen . . .	128·0	52·29	52·35
	244·8	100·00	100·00

A very fine purple lead salt, which had been dried at 250°, gave the following results: From 2·648 of material were obtained 1·226 of carbonic acid, and 0·261 of water. 1·261 of material gave 0·158 of oxide of lead, and 0·661 of metallic lead.

The formula $C_{18}H_7O_{16} + 5 PbO$ gives

	Theory.		Experiment.
18 Carbon . . .	109·8	13·69	12·81
7 Hydrogen . . .	7·0	0·75	1·09
16 Oxygen . . .	128·0	15·97	16·10
5 Oxide of lead . .	558·0	69·59	70·00
	802·8	100·00	100·00

When this salt is dried at 180° it retains about 3.5 per cent. of water, which it loses at 250° . In this hydrated form, its constitution is probably $C_{18}H_7O_{16} + 5 Pb O + 3 Aq$.

With oxide of silver the spaniolitmine gives a fine purple lake, which gradually becomes black on exposure to light. It was analysed.

0.894 of a portion dried at 212° , gave by ignition 0.482 of metallic silver.

1.762 gramme of the same specimen gave 1.206 of carbonic acid, and 0.271 of water. These numbers give the formula $C_{18}H_7O_{16} + 3 Aq O$.

	Theory	Experiment.
18 Carbon . . .	109.8	18.92
7 Hydrogen . . .	7.0	1.61
19 Oxygen . . .	152.0	25.55
3 Silver . . .	324.0	53.92
	592.8	100.00
	100.00	

If the solution of spaniolitmine in water of ammonia be decomposed by basic acetate of lead, there is produced a fine azure-blue precipitate, which is not altered by an excess of ammonia; and as it appeared to contain almost exactly the same quantity of oxide of lead, in portions prepared at different times, it was looked upon as being definite in constitution, and was analysed.

A. 1.762 gramme of substance dried at 250° in an oil bath, gave 0.520 of oxide of lead, and 0.900 of metallic lead, being 85.35 Pb O in 100.

B. 2.161 gramme of another portion, dried also at 250° in an oil bath with LIEBIG'S apparatus, gave 1.159 of metallic lead, and 0.558 of oxide of lead, equivalent to 84.31 Pb O in 100.

C. 3.558 gramme of the same specimen gave 0.152 of water, and 0.846 of carbonic acid.

The formula which results is $C_{18}H_7O_{16} + 12 Pb O$.

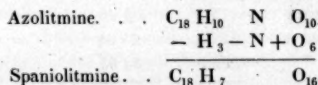
	Theory.	Experiment.
18 Carbon . . .	109.8	6.58
7 Hydrogen . . .	7.0	0.43
16 Oxygen . . .	128.0	8.68
12 Oxide of lead .	1339.2	84.31
	1584.0	100.00
	100.00	

If this substance be dried at the temperature of 150° it retains five per cent. of water, which it loses completely between 212° and 250° . This quantity is almost exactly nine equivalents, and hence probably the hydrated salt is $C_{18}H_7O_{16} + 12 Pb O + 9 Aq$, or $C_{18}H_7O_{16} + 3 Pb O + 9 (Pb O Aq)$.

The result of these different analyses justify, in my opinion, fully the formula which I have adopted for their expression. It might perhaps be urged that in the analysis of the silver salt, there was obtained too much carbon by 0.39 per cent., and that this

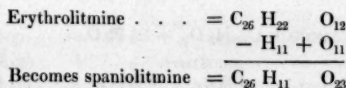
being so unusual a direction for the analysis of an organic substance to vary from the truth, a modification of the formula should be adopted. I consider, however, that where the formula gives, in the other instances, results so very consonant to experiment, there may be in that one case some little inaccuracy of weighing suspected, particularly as the excess of hydrogen is also in some degree greater than should be found in the analysis of a substance that had been so well dried.

Another reason for the adoption of the formula $C_{18}H_7O_{16}$ is, that it accounts most easily for the formation of this substance at the expense of the azolitmine; the azolitmine losing an equivalent of ammonia and gaining six equivalents of oxygen. Thus



the replacement being regular; for as the hydrogen and azote do not exist as ammonia in azolitmine, they are, although perhaps evolved as ammonia, separately replaced, the three equivalents of hydrogen making way for three of oxygen, and the nitrogen being equivalent to three equivalents of oxygen also, as has been fully proved by the Researches of LAURENT and of others. Indeed, if azolitmine be considered as the source from whence the spaniolitmine is derived, no other formula can well be taken, for any change in the number of equivalents of carbon would render the decomposition unnecessarily complicated.

If, however, the spaniolitmine be supposed to originate in the decomposition of erythrolitmine, a formula may be adopted at once deducible by the simplest considerations of substitution, and agreeing fully as well as that previously given with the analytical results. Thus



The calculated results of this formula I subjoin, in order that they may be compared with the experimental numbers, and with those given by the other theory.

$C_{26}H_{11}O_{23}$.	
$C_{26} = 158.6$	44.85
$H_{11} = 11.0$	3.11
$O_{23} = 184.0$	52.04
353.6	100.00

$C_{26}H_{11}O_{23} + 4 \lg O$.	
$C_{26} = 158.6$	19.40
$H_{11} = 11.0$	1.34
$O_{27} = 216.0$	26.42
$Ag_4 = 432.0$	52.84
817.6	100.00

These results agree better with experiment than those given by the other view, but the constitution of the purple lead salt is opposed to it, as, the organic substance in the purple lead salt being $C_{26}H_{11}O_{23}$, the oxide of lead amounts to seven and a half

equivalents, which can scarcely come within the limits of experimental error. The basic lead salt agrees well with $C_{26} H_{11} O_{23} + 16 Pb O$.

It would be very wrong, with the limited data which were in my power to obtain, to fix decidedly upon one of these formulæ to the absolute exclusion of the other. They both account for the existence of spaniolitmine completely, and the latter simply. For the elimination of the azote from bodies such as those now being described occurs but rarely, and should not consequently be supposed to occur in cases where it can be avoided. I leave, therefore, to future investigators in this field the determination of whether the equivalent of spaniolitmine should be considered $C_{18} H_7 O_{16}$, or $C_{26} H_{11} O_{23}$.

Section IV. *Of the Decolorization of the Bodies which exist in Archil and in Litmus.*

The various coloured substances which have been described in the preceding sections, will now require to be considered in some points of view, which being common in a great degree to all, would have led to useless repetition had their discussion been entered upon in the case of each individual substance. I have reserved, therefore, to the present stage of the investigation all general considerations, and shall now proceed to the examination of such points of their history as yet remain unnoticed.

The question as to whether the proper colour of litmus be red or blue, may now be considered as finally set at rest, and the theory of those changes of colour which have from so early an age in chemistry served for the recognition of alkaline or acid properties, is definitely laid down. Among the various suppositions made from time to time by chemists as to the nature of litmus, the idea of PEARCETI has ultimately been proved to be the most correct, although, as his views were not supported by any accurate experiment, no positive value could be attached to his opinion. Litmus is reddened by acids, because these acids remove the loosely combined ammonia by which the blue colour is produced, and the so-called hydrogen acids liberate the colouring matter, inasmuch as they combine with the alkali to form bodies (chlorides or iodides) with which the colouring matter has no tendency to unite. Thus the mysterious reddening of litmus paper, by which so many chemists of narrow ideas imagined that the most cogent philosophical proofs of the basic power of the compounds of hydrogen might be evaded, is found to be merely produced by the chloride of hydrogen, &c. forming on potash chloride of potassium, and with ammonia sal-ammoniac, and the proper red colouring matter becoming free. It is thus sufficiently shown that the reddening of litmus is no proof that chloride of hydrogen is an acid, but that the double decomposition which occurs is the same in principle, whether hydrogen or a fixed metal come into play, thus taking azolitmate of ammonia and chloride of hydrogen upon the one hand, and azolitmate of ammonia and chloride of copper on the other; the decompositions are

first, $(C_{18} H_{10} N O_{10} + N H_4 O) + Cl H. = (C_{18} H_{10} N O_{10} + H O) + Cl N H_4;$

and second, $(C_{18} H_{10} N O_{10} + N H_4 O) + Cl Cu = (C_{18} H_{10} N O_{10} + Cu O) + Cl N H_4.$

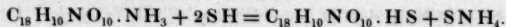
The bodies $C_{18}H_{10}NO_{10} \cdot HO$, and $C_{18}H_{10}NO_{10} \cdot CuO$, differ in solubility and colour, but are generated by reactions identical so far as principle is concerned.

Are the coloured substances in archil and litmus themselves acids? This is a question which I consider as being of very little consequence to science, particularly as the word acid has by the progress of research been deprived of almost all definite meaning in philosophic language, and can scarcely be used except for purposes of familiar illustration. These various substances do not redden litmus, but if browned turmeric paper be brought into contact with one of the red litmus bodies, the alkali is divided between the red and the yellow material, and the browning of the one diminishes according as the other becomes blue. Whichever colouring matter is in excess preponderates, and hence I consider that the usual characters of acidity are so slightly marked, as to render it more suitable to adopt the indifferent termination in *ine*, which I have used for all of the substances described in this paper except one. This is the erythroleic acid, and if chemists approve of the mode of distinction proposed for the two orceines, I should prefer indicating the difference between the erythroleins in a similar way. The erythroleic acid should then be beterythrolein, and the other alpherythrolein. Whatever nomenclature chemists in general may adopt, I shall myself willingly accede to.

One of the most singular and obscure properties of these colouring matters, is that of becoming colourless under a variety of circumstances, and of generating a series of compounds, which are white whilst they remain unchanged, but which, on exposure to the air, become coloured, and assume their original condition. These effects may be produced in many ways, of which I shall notice the more important.

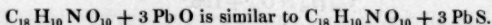
It is long known that sulphuretted hydrogen possesses the property of blanching litmus, but chemists are not agreed as to the precise manner in which it takes place. Some refer it to a deoxidation effected by the hydrogen, like that which the same gas produces on salts of the peroxide of iron; others, and as I have found more accurately, look upon the sulphuretted hydrogen as combining unaltered with the colouring material; these chemists being, however, in error in supposing the colouring matter to be blue. The grounds on which I base my opinion of the nature of this phenomenon are the following.

First. If a perfectly clear solution of an alkaline salt of a litmus or archil body be treated with pure sulphuretted hydrogen, a colourless and scarcely opalescent liquor is obtained, the quantity of sulphur deposited being nothing, or almost inappreciable. This liquor contains an alkaline sulphuret, as may be proved by its action on a salt of iron or of manganese. If it be boiled, the sulphuretted hydrogen is given off, and the liquor becomes reddish, but very long boiling, or else exposure to the air, is necessary, that it may become fully red. It cannot be completely restored to its original blue or violet colour without the addition of some more alkali. Taking azolitmine as the standard, the reaction evidently is



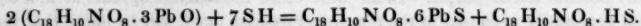
Second. If a solution of persulphuret of calcium or of sulphuret of barium be mixed with a solution of a blue litmus liquor, no loss of colour results. Some blue azolitmate of lime or of baryta is deposited, but no decolorization occurs. On the addition of an acid, there is an immediate disengagement of sulphuretted hydrogen, and the blue colour at once disappears.

Third. If azolitmate of lead be treated by a current of sulphuretted hydrogen, it is converted into a black powder undistinguishable in colour from sulphuret of lead. This powder may be boiled in water without being decomposed, but by protracted boiling or washing it yields azolitmine, though very sparingly. When treated with solution of potash or ammonia, a deep blue liquor is immediately obtained, and sulphuret of lead remains behind. It is, therefore, a positive chemical compound of azolitmine and sulphuret of lead corresponding to that containing the oxide of that metal; thus



This black substance cannot be azolitmine precipitated and mixed mechanically with sulphuret of lead, for water of sulphuretted hydrogen dissolves azolitmine better than pure water. In this compound also the colour of the azolitmine is completely lost, as when it combines with sulphuretted hydrogen in solution.

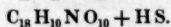
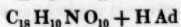
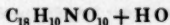
Fourth. If in place of azolitmine the betaorceine in combination with oxide of lead be acted upon by sulphuretted hydrogen, the evidence is perfectly decisive that the black substance produced is a compound of orceine and sulphuret of lead. It may be boiled in alcohol without yielding up a trace of colouring matter, but when treated with water of ammonia it is immediately decomposed, the usual rich purple liquor being produced. It is remarkable, however, that an excess of sulphuretted hydrogen has, on the betaorceinate of lead, the same effect which ammonia would have, that is, to produce a more basic salt. Thus if the betaorceinate of lead be diffused through water and treated with sulphuretted hydrogen, a considerable quantity of betaorceine will be found in the colourless liquor combined with sulphuretted hydrogen, the reaction being



Fifth. A point of considerable interest as involved in the action of sulphuretted hydrogen on these colouring matters, is to ascertain whether in the decolorized form there might not be a certain quantity of the oxygen of the substance replaced by sulphur. Thus, that from $\text{C}_{18}\text{H}_{10}\text{NO}_{10} + \text{SH}$ there might be formed $\text{C}_{18}\text{H}_{10}\text{NO}_9\text{S} + \text{H}_2\text{O}$. That this does not take place, is fully shown by the constitution of the compounds with the metallic sulphurets. On destroying, by means of nitric acid, the compounds of betaorceine and of azolitmine with sulphuret of lead, I found that neutral sulphate of lead was formed, and that the liquors contained no trace of sulphuric acid. The sulphur was, therefore, only in sufficient quantity to convert the lead into sulphuret, and hence the oxygen of the organic substance is not in any degree replaced by sulphur.



It results from these experiments, that precisely as the colouring matters combine with water to form different shades of red coloured bodies—with ammonia (amidide of hydrogen) to produce a series of bodies which are blue or purple—so they combine with sulphuret of hydrogen to form colourless compounds in solution, which, if solid, would very probably be white. I attempted frequently to obtain these compounds solid, but without success, the sulphuretted hydrogen escaping at ordinary temperatures, and the substance being soluble both in water and in spirit, rendered my trials useless. The equivalency of these three series of bodies is evident, however, when we compare



The similarity of character which pervades oxygen, amidogene, and sulphur is manifest in other departments of organic chemistry; precisely therefore as these colouring matters combine with metallic oxides and metallic sulphurets, so may we expect to discover at some future period, bodies consisting of them in union with metallic amidides.

In addition to the action of sulphuretted hydrogen, the colouring matters of litmus may be blanched by other deoxidizing agents of a very distinct character, and whose action it will be of the highest interest to be able to study in detail. It had been long known that by means of nascent hydrogen, the colours of a great variety of flowers might be removed, and I have found that in this way all the various colouring substances of litmus and of archil may be rendered white, and converted into new bodies, an exact examination of which is very difficult. The coloured bodies may also be reduced to the white condition by means of those metallic oxides which powerfully attract oxygen, as the protoxides of tin and iron, and in these white conditions they combine with the various bases to form salts or lakes, which on exposure to the air, rapidly become red or purple. In all these cases the reaction appears at first sight almost necessarily to consist in the removal of oxygen, but it will be found that there is very full evidence against that opinion, and that in reality the change results from the addition of a certain quantity of hydrogen to the substance. These white substances I propose to indicate by the initial word *Leuco* (from λευκος, *white*), and there is no doubt but there exists one for each coloured matter, but I have only obtained numerical or exact results with two, the leucolitmine formed from azolitmine, and the leucorceine formed from the betaorceine.

When a solution of orceine in water of ammonia is rendered slightly acid by muriatic acid, and a slip of zinc immersed in it, the liquor becomes after some time perfectly colourless, but recovers its original red tinge rapidly when exposed to air. If to the colourless solution water of ammonia be added, a copious white precipitate is produced, which very soon becomes pink, and ultimately purple, on exposure. To

examine this precipitate in its white form, it was immediately, on being formed, thrown upon a filter and placed under the receiver of an air-pump, from which the air was removed, and then it was filled with carbonic acid gas. As soon as the liquor had filtered through, the filter was filled with warm distilled and recently boiled water, and the replacement of the air, by carbonic acid gas, again proceeded with. This was continued until the substance was found to have been washed enough.

A dish of oil of vitriol was then placed under the receiver, and the vacuum maintained until the precipitate had become completely dry. In no case did I succeed in obtaining the precipitate white when dry. Most frequently it was spoiled altogether, becoming purple. But in a case where I obtained it of a uniform pale pink colour, it was analysed.

0.451 gramme of substance gave, by ignition until all organic matter was burned off, then moistening with nitric acid, and again igniting, 0.157 of oxide of zinc.

0.382 gramme of substance gave 0.439 of carbonic acid, and 0.160 of water.

The formula resulting is $C_{18}H_{14}O_{10}N + 3ZnO$, by which the numbers obtained are

		Theory.	Experiments.
18 Carbon . .	109.8	32.41	31.80
14 Hydrogen . .	14.0	4.13	4.66
1 Nitrogen . .	14.1	27.77	28.73
10 Oxygen . .	80.0		
3 Oxide of zinc	120.9	35.69	34.81
	338.8	100.00	100.00

This formula may be rationally assumed as either $C_{18}H_{10}NO_6 + 3ZnO + 4HO$, or $C_{18}H_{12}NO_8 + 3ZnO + 2HO$, the decolorized condition being supposed due to either a loss of oxygen or gain of hydrogen. In order to compare it with the ordinary betarceinate of zinc, a specimen of fine purple salt was analysed. It had been carefully dried at 212°Fahr.

0.982 gramme gave, by ignition and treatment with nitric acid, 0.331 of oxide of zinc.

0.651 gramme gave 0.235 of water, and of carbonic acid 0.720.

The resulting formula is $C_{18}H_{14}NO_{12} + 3ZnO$, from which result the numbers:

		Theory.	Experiment.
18 Carbon . .	109.8	30.95	30.53
14 Hydrogen . .	14.0	3.95	4.02
1 Nitrogen . .	14.1	31.03	31.73
12 Oxygen . .	96.0		
3 Oxide of zinc	120.9	34.07	33.72
	354.8	100.00	100.00

This formula, $C_{18}H_{10}NO_8 + 3ZnO + 4aq$, is completely analogous to that of the betaorceinate of copper, which was found to be $C_{18}H_{10}NO_8 + 3CuO + 4aq$.

The white orceinate of zinc differs from the purple variety in containing two equivalents of oxygen less, but the above analyses cannot be considered as fully deciding whether the substance in an anhydrous form is expressed by the formulæ $C_{18}H_{12}NO_8$, or $C_{18}H_{10}NO_6$. To obtain more complete evidence, leucorceinate of zinc (the same specimen as that analysed) was exposed in LIEBIG's apparatus to a stream of dry carbonic acid in an oil bath, heated to 280° of FAHR., until long after all traces of water had passed away, and the bulb-tube containing the substance had ceased to lose weight. In this experiment 0.547 of material gave 0.030 of water, being 5.48 per cent., and the remaining 0.517 gave, by careful ignition until all organic matter was removed, moistening with nitric acid, and ignition a second time until all traces of nitrous fumes were driven off, 0.193 gramme of oxide of zinc, corresponding to 35.39 per cent. Taking the dry leucorceine as $C_{18}H_{10}NO_8 + 2H$, the numbers are

	Theory.		Experiment.
1 Leucorceine	199.9	59.00	59.13
2 Water . .	18.0	5.31	5.48
3 Oxide of zinc	120.9	35.69	35.39
	338.8	100.00	100.00

The quantity of oxygen separable in the form of water, is therefore fully shown to be two equivalents, and hence the formation of the leucorceine is due to the fixation of hydrogen in the new body, and not to the abstraction of oxygen from the old.

When a solution of protochloride of tin is added to azolitmine dissolved in water of ammonia, a fine purple precipitate falls, which having been well washed and dried in a temperature of 212° in LIEBIG's apparatus, was analysed as follows.

0.547 gramme ignited and treated with nitric acid, as in former instances, gave 0.231 of peroxide of tin.

0.631 gramme gave 0.202 of water, and 0.681 of carbonic acid.

The formula deducible from these results is $C_{18}H_{12}NO_{12} + 2SnO$, this salt containing only one half of the protoxide of tin existing in the protazolitmate of tin, described under the head of azolitmine. The numerical results are

	Theory.		Experiment.
18 Carbon .	109.8	30.03	29.86
12 Hydrogen	12.0	3.28	3.55
1 Nitrogen .	14.1	3.85	33.37
14 Oxygen .	112.0	30.63	
2 Tin . .	117.8	32.21	33.22
	365.7	100.00	100.00

It is probable that this azolitmate of tin may be the more definite of the two, as possibly an excess of ammonia may have produced the formation of the more basic salt formerly described. When this salt, diffused through water, is mixed with a small quantity of muriatic acid and boiled for some time, it becomes whitish or slightly fawn-coloured, and the tin is found to have been changed into peroxide. A quantity of the tin makes its appearance as peroxide uncombined, but the greater part remains united with the leucazolitmine. I found the difficulties of procuring this compound in its white form proper for analysis, to be insuperable. Even in the best exhaustions I could produce, it gradually became red; and when exposed even for a short time to the air, it forms a bright scarlet lake, remarkably distinct from that produced by the protoxide of the same metal. I consequently was not able to analyse the leucazolitmate of tin, or to obtain at all the same evidence concerning it that I did with regard to leucorceine.

I allowed a quantity of leucazolitmate of peroxide of tin diffused through water, to lie exposed to the air in a flat dish until it was completely converted into the scarlet substance. This was then dried at 212° and analysed, there being some peroxide of tin mechanically diffused through it, but not much.

0.652 gramme gave water 0.215, and 0.658 of carbonic acid.

1.107, by ignition and treatment with nitric acid, gave 0.443 of peroxide of tin.

The resulting formula is $C_{18}H_{12}NO_{16}Sn_2$, giving

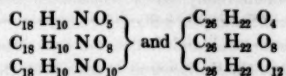
Theory.		Experiment.
18 Carbon .	109.8 28.77	27.93
12 Hydrogen .	12.0 3.14	3.66
1 Nitrogen .	14.1 3.69	36.93
16 Oxygen .	128.0 33.54	
2 Tin .	117.8 30.86	31.48
	381.7 100.00	100.00

This salt, exposed to a temperature of 280° in an oil bath, loses 4.5 of water or two equivalents, and hence when dry is $C_{18}H_{10}NO_{10} + 2SuO_2$.

The blanching of azolitmine by hydrogen can easily be effected by precisely the same means as were described under leucorceine, but the restoration of the colour occurs so rapidly and from such slight access of air, that it must be considered as still more difficult to isolate the white condition than the orceine. I consequently was not able to analyse the leucazolitmate of zinc, and the proofs of its being similar in constitution to leucorceine must rest on analogy alone.

An additional reason for looking on these bodies as being produced by the addition of hydrogen and not by the abstraction of oxygen, is the fact, that where there are so many formed by the absorption of oxygen from the same source, the subsequent removal of oxygen should regenerate the bodies lower in the scale, in place of produ-

cing a series of new bodies totally different in colour. Thus, as by exposure to oxygen, there are produced



so by exposure to hydrogen, the same series should be re-produced in the inverse order, if it act only by removing oxygen. This, however, does not take place; on the contrary, it appears that as from $\text{C}_{18} \text{H}_{10} \text{N O}_8$, there is formed by oxygen $\text{C}_{18} \text{H}_{10} \text{N O}_{10}$, so there is by hydrogen $\text{C}_{18} \text{H}_{10} \text{N O}_8 \text{H}_2$, and perhaps from $\text{C}_{18} \text{H}_{10} \text{N O}_5$, $\text{C}_{18} \text{H}_{10} \text{N O}_5 \cdot \text{O}_3$, and $\text{C}_{18} \text{H}_{18} \text{N O}_5 \cdot \text{H}_3$, and from $\text{C}_{18} \text{H}_{10} \text{N O}_{10}$ hydrogen forms $\text{C}_{18} \text{H}_{10} \text{N O}_{10} \text{H}$. I conceive that in this way alone can a satisfactory explanation of all the facts be given. That deoxidation is not the characteristic process, obtains also probability from the fact, that neither sulphurous acid, nor a solution of a sulphite, has any effect upon azolitmine, either free or in alkaline combination. The sulphurous acid reddens litmus as any other acid, but has no power whatsoever to remove its colour.

There is no circumstance, in the history of the colouring bodies, of more interest than that of the bleaching powers of chlorine; whether considered as affording the theory of a process, so long and so deservedly esteemed one of the most important applications of chemistry to the arts, or examined with regard to testing by its means the generality and exactness of the important views recently deduced, concerning the constitution of organic bodies, from the results of the action of chlorine upon them, by studying in a new class of substances, how far the principle on which it acts may be modified or confirmed. Before the study of organic chemistry had attained the accuracy which it now possesses, chlorine was considered to bleach by decomposing water, with the hydrogen of which it entered into combination. The oxygen being thus set free, was supposed to act in its nascent form with peculiar power upon the colouring matter, and thus to produce in a few minutes the same effect as should have resulted, though much more slowly, from the action of air and moisture. When the action of chlorine on organic substances became more minutely studied, it was found that a portion of chlorine entered into the constitution of the new substance formed by its action, and it was natural to suppose that such should be the case in bleaching also. This idea appears to have been first distinctly advanced by ROBIQUET in the article Blanchiment, in the Dictionnaire Technologique, in 1823; but as he did not rest it on any experimental evidence, it did not attract attention, and I was not aware that the true theory of bleaching had been suggested by that chemist until these researches were almost quite complete.

In addition to the principle of the fixation of chlorine in the resulting compound, there is another point to be attended to in researches like the present, and which will be found of high interest in a theoretical point of view. In the generality of organic bodies, the fixation of chlorine is accompanied by loss of hydrogen, usually to an

equivalent amount, and it is known that on this principle is founded the law of substitutions, proposed by DUMAS, and which has led that illustrious chemist to his theory of organic types, which now occupies so much the minds of chemists. Now it is a question, does this replacement of hydrogen occur in bleaching? are the colouring matters similar to other organic substances in that respect? or do they, particularly when containing azote, follow other and peculiar laws? To the solution of these questions, the following experiments were directed.

1st. Action of chlorine on betaorceine.

When chlorine is brought into contact with pure betaorceine, diffused through water, or still better, in solution in an ammoniacal liquor, the colour gradually alters until the whole is changed into a brownish yellow substance insoluble in water. To this substance I give the name of *Chlororceine*. As soon as all the orceine is decomposed, the current of chlorine should be stopped, as by a great excess of chlorine the composition of this body is subject to be altered. The chlororceine is insoluble in water; soluble in alcohol and ether; also in water of ammonia, forming a deep yellowish brown liquor, from which it is again precipitated by acids, though not without being changed. This ammoniacal liquor is also precipitated by metallic salts, forming compounds which probably contain some form of chlororceine, but which have not been more minutely examined.

The chlororceine, simply prepared and dried at 212° FAHR., was analysed.

A. 0.700 of material gave by ignition with carbonate of soda, and precipitation with nitrate of silver, 0.766 of chloride of silver.

0.576 of material gave 0.227 of water, and 0.842 of carbonic acid.

Another specimen being examined,

B. 0.842 grammes gave 0.887 of chloride of silver.

0.543 grammes gave 0.782 of carbonic acid, and 0.210 of water.

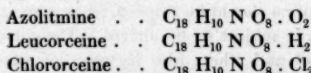
Hence the composition in 100 parts.

	A.	B.	
Carbon	40.35	39.82	} 100.00
Hydrogen	4.38	4.31	
Oxygen and Nitrogen	28.27	29.87	
Chlorine	27.00	26.00	

The formula $C_{18}H_{10}NO_8Cl_2$, gives

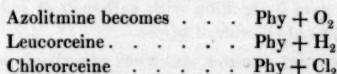
18 Carbon	109.8	40.86
10 Hydrogen	10.0	3.72
8 Oxygen	64.0	} 29.07
1 Nitrogen	14.1	
2 Chlorine	70.8	26.35
	268.7	100.00

In the production of this substance there are therefore two equivalents of chlorine directly added to the betarorceine, and the proportion of hydrogen proves that in this case no replacement of hydrogen occurs. This is further shown by the fact, that in the action of chlorine on pure orceine, there is produced a mere trace of hydrochloric acid. The relation of the carbon and the nitrogen has been assumed as being unaltered by the action of the chlorine: this I have not directly proved completely; indeed, for some time I believed that a portion of the nitrogen was eliminated by the chlorine, as sal-ammoniac, but although the small quantity of orceine at my disposal prevented me from fully ascertaining the relation to remain eighteen to one, yet in a trial which I made it appeared so nearly that, that I believe it may be looked upon as sufficiently determined to be made the basis of the formula. I therefore look upon chlororceine as being $C_{18} H_{10} N O_8 Cl_2$, and I consider the bodies



as being similar to one another, and belonging to the same family or organic type.

It is evident that the betarorceine itself might be looked on as a sort of compound radical, of which the azolitmine would be the oxide, and the others respectively the hydruret and chloride. Thus calling betarorceine, from its purple colour, *Phenyl*. = *Phy*.



It is adverse to this view, that the bodies, which we consider to be compound radicals, do not possess the property of combining with metallic oxides, as orceine has been found to do. The action of alkalies on chlororceine is also opposed to this simple view.

When chlororceine is dissolved in solution of potash, or of ammonia, there is formed a certain portion of metallic chloride, and on the addition of an acid, a substance is precipitated rather darker coloured than the chlororceine had been originally, but otherwise identical with it in properties. In composition, this substance differs remarkably from chlororceine; the proportion of chlorine remaining in it is not always the same, the chlororceine appearing to dissolve at first without alteration, but by boiling for some time, being decomposed in a complex manner, giving an alkaline chloride and two organic substances, which differ in solubility, though not very much. On this account, the analyses made of this precipitated substance do not agree well among themselves, and I shall here introduce the analysis of a specimen in which the decomposition appeared to be most complete, only for the purpose of pointing out the direction of the result, and perhaps its approximate value. It was the more soluble portion which was analysed.

0.525 gramme, dried at 212° , gave 0.200 of water, and 0.788 of carbonic acid.

1.225 gave 0.653 of chloride of silver.

These results are expressed by the formula $C_{18}H_{10}NO_{12}Cl$, the numbers being

	Theory.		Experiment.
18 Carbon. . .	109.8	41.38	41.51
10 Hydrogen. . .	10.0	3.77	4.23
1 Nitrogen . . .	14.1	41.50	41.11
12 Oxygen . . .	96.0		
1 Chlorine . . .	35.4	13.35	13.15
	265.3	100.00	100.00

It is not easy to see how this compound arises directly from the chlororceine, and it can only be in virtue of a very complex decomposition. The portion, which dissolves less easily in water of ammonia, not having been analysed, its constitution can only be surmised. If all the chlorine had been removed by the alkali, and replaced by oxygen, it is evident that azolitmine should be produced, which is certainly not the case; and I hence consider that by the action of the alkali one half of the chlorine is removed, and a substance generated, expressed by the formula $C_{18}H_{10}NO_9Cl$, which being subsequently decomposed by the excess of alkali may be supposed to break up into $C_{18}H_{10}NO_6Cl$, and $C_{18}H_{10}NO_{12}Cl$, of which the latter is that analysed. I throw out this suggestion without attaching much weight to it, for although it is not likely that the true theory is far from that now described, yet the study of this reaction is of course very incomplete.

Action of Chlorine on Azolitmine.

By the action of chlorine on azolitmine, there is produced a peculiar yellow substance, insoluble in water, soluble in alcohol and ether; soluble also in alkalies, from whence it is precipitated unchanged by the addition of an acid. It is capable of uniting, by means of double decomposition, with metallic oxides and forming salts. The name of chlorazolitmine may be applied to it.

Its analysis gave the following results:

A. 0.217 gramme gave 0.123 chloride of silver.

0.314 gramme gave 0.498 of carbonic acid, and 0.133 of water.

B. 0.859 of another portion, dried at 212° FAHR., gave 0.511 of chloride of silver.

0.535 gramme gave 0.834 of carbonic acid, and 0.221 of water.

The composition in 100 parts is hence

	A.	B.	
Carbon	43.95	43.13	100.00
Hydrogen	4.70	4.59	
Oxygen and Nitrogen . . .	37.39	37.60	
Chlorine	13.96	14.68	

Whence the formula $C_{18} H_{10} N O_{10} Cl$; and the reaction appears to be extremely simple, consisting in the addition of an equivalent of chlorine without any elimination of hydrogen. The numbers deduced from the formula are

18 Carbon. . .	109·8	44·04
10 Hydrogen. . .	10·0	4·01
1 Nitrogen . . .	14·1	37·75
10 Oxygen . . .	80·0	
1 Chlorine . . .	35·4	14·20
	249·3	100·00

The leucazolitimine, if it could have been analysed in a pure condition, would very probably have been found similar in constitution to chlorazolitimine. The bodies $C_{18} H_{10} N O_{10} \cdot H$, and $C_{18} H_{18} N O_{10} \cdot Cl$ being to each other as $C_{18} H_{18} N O_8 \cdot H_2$, and $C_{18} H_{10} N O_8 \cdot Cl_2$.

Action of Chlorine on Erythrolitimine.

When erythrolitimine is diffused through water, and a current of chlorine passed through it, it changes into a buff-coloured substance, which is insoluble in water, and resembles all the other bodies, formed by the decolorizing action of chlorine upon these colouring matters, in its general properties. It may be termed chlorerythrolitimine, and was analysed after having been dried at 212° in LIEBIG's apparatus.

A. 0·412 gramme gave 0·118 of chloride of silver.

0·433 gramme gave 0·896 of carbonic acid, and 0·318 of water.

B. 0·732 of another specimen gave 0·197 of chloride of silver.

0·365 gave 0·759 of carbonic acid, and 0·270 of water.

The resulting composition per cent. is

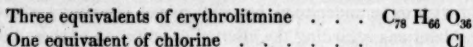
	A.	B	
Carbon. . . .	57·24	57·51	100·00
Hydrogen. . . .	8·15	8·22	
Oxygen. . . .	27·56	27·62	
Chlorine	7·05	6·65	

Hence results the formula $C_{52} H_{44} O_{19} Cl$, giving

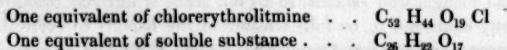
52 Carbon. . . .	317·2	57·82
44 Hydrogen. . . .	44·0	8·02
19 Oxygen. . . .	152·0	27·71
1 Chlorine	35·4	6·45
	548·6	100·00

This result is very singular, inasmuch as the chlorine compound contains less oxygen than that from which it had been formed, and also that two equivalents of erythrolitimine are involved in the decomposition which fixes one of chlorine. This may

be, however, in great part explained by the fact, that at the same time with the chlorerythrolitmine there is produced another body, soluble in water, but which I have not yet obtained in a form proper for analysis. On this soluble substance I consider the oxygen lost by the chlorerythrolitmine to be fixed; and although it has not as yet been analysed, an idea of its probable constitution may be formed, if we consider it to be produced as follows:

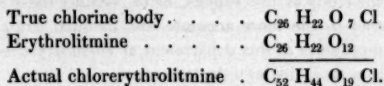


may be considered to produce



It is possible that this soluble substance may contain in addition a quantity of chlorine.

The chlorerythrolitmine itself I conceive to be a compound of unaltered erythrolitmine, with the true chlorine substance. Thus



The true erythrolitmine is thus indicated to be erythrolic acid, in which an equivalent of oxygen is replaced by chlorine, $C_{26} H_{22} O_8$ resembling $C_{26} H_{22} O_7 Cl$.

The very small quantity of chlorine which exists in chlorerythrolitmine, renders it exceedingly difficult to say, from analysis, whether hydrogen is removed or not. I do not consider myself justified in believing any loss of hydrogen to occur, in the absence of proof that it has occurred, particularly as in the other cases of the colouring matters now examined, it positively does not take place.

In acting on the bodies now described, it appears therefore that chlorine is subjected to conditions, different from those which determine the nature of the results with the generality of organic bodies, and that the replacement of hydrogen, so marked in other cases, does not exist in the class of substances under consideration. On the contrary, the action of the chlorine would appear to lend support to the idea, that as among inorganic bodies chlorine may combine either directly with metallic oxides, or else, in decomposing them, generate a higher degree of oxidizement and a chloride of the metal; so the colouring matters, at least those now examined, may be looked upon as being similarly affected, and that in reality the products of the bleaching energy of chlorine on a coloured substance, resemble in constitution the compounds of chlorine which possess bleaching powers. Thus as CaO combines with chlorine, so may azolitmine; and the bodies $CaO \cdot Cl$ and $AzI \cdot Cl$ correspond. Also, as in a peroxide some oxygen may be replaced by chlorine, as in the bodies PbO_2 and

Pb O Cl , Ba O_2 and $\text{Ba O} \cdot \text{Cl}$; so from orceine, the bodies chlororceine and azolitmine may be formed of similar constitution.

I have already pointed out my reasons for considering these different series of coloured bodies as consisting not of the same organic radicals, combined with different quantities of oxygen, but as being, though formed in succession by gradual oxidation, when once produced, independent of each other, and not reducible to any common type. I should wish to be understood, however, as not insisting positively upon any theoretical considerations regarding the internal constitution of these bodies; I have met with too many difficulties in their investigation, and have seen too often ideas which I had thought well established by one series of analyses overturned by those subsequently made, not to be fully sensible of the liability to correction, to which even my present opinions may be subject. Among substances, so numerous, so similar in properties, and so variable in constitution; in a field of investigation which for numerical or accurate purposes must be looked upon as previously unexplored, it would be inexcusable rashness and presumption in me, not to look forward to the correction of my results in many instances, by those chemists who may hereafter devote themselves to the study of this subject, or to consider these researches as being more than introductory to the more accurate and detailed examination, which the great fertility and importance of this department of chemistry deserves, and, I trust, is likely to obtain from more distinguished chemists.

Royal Dublin Society,
April 21st, 1840.

XVI. *On the influence of Iodine in rendering several Argentine Compounds, spread on Paper, sensitive to Light, and on a new Method of producing, with greater distinctness, the Photographic Image.* By Mr. ROBERT HUNT. Communicated by Sir J. F. W. HERSCHEL, Bart., K.H. V.P.R.S. &c. &c.

Received May 13,—Read June 18, 1840.

THE magical perfection of the designs delineated by light on the prepared tablets of M. DAGUERRE, and the extreme sensitiveness of his photographic material, render the discovery of inappreciable value to art and science. It appeared to me unfortunate, that a process which promised to improve our perceptions of the beautiful, and which placed in the hands of the scientific observer an instrument of wonderful delicacy, should have its utility circumscribed by its expense and inconvenience.

Had the art of engraving the Daguerreotype tablets, or any other mode of multiplying copies of the original designs been discovered, nothing further would have been desired; but as it was, it appeared to be of the greatest importance, that means should be sought for of using some lighter and less expensive material.

Even M. ARAGO, when speaking on the Report of the Commission on DAGUERRE's pension, remarks, "It had unquestionably been preferable, for the convenience of travellers, and also on the score of economy, could paper have been here employed."

It will, without doubt, occur to all, that the original photographic processes discovered by Mr. Fox TALBOT, and published by that gentleman some time prior to the disclosure of DAGUERRE's secret, were on paper; and, though compelled to admit the superior beauty, the infinite minuteness of detail, and the charm of the aerial effect, in the pictures drawn on the polished tablets, yet, it must be allowed, the great end of the art being the multiplication of an indefinite number of fac-similes of original drawings, we can only expect to arrive at it by following in the steps of our talented countryman, whose recent productions, with the sight of some of which I have been favoured by the extreme kindness of Sir JOHN HERSCHEL, are of the richest promise. To Mr. TALBOT, therefore, we must concede the high merit of being the discoverer of the photographic processes, which will, probably, ultimately turn out the most convenient and most extensively useful.

By a careful examination of the means employed to give the required sensitiveness to the silver surface, particularly the application of heat, and the subsequent rubbing with nitric acid, which performs a more important part than merely polishing, I was convinced of the possibility of covering paper with a preparation on which the iodine and mercury might operate as they are found to do upon the plate of metal.

This led to many experiments, and as I consider that the results arrived at are of considerable scientific importance, I shall, without apology, proceed to detail a series of experimental observations, which, it appears to me, promise to extend the principles of photography to purposes of high interest and of much utility.

1. M. DAGUERRE has stated, that a solid silver plate is less effective than one of copper plated with silver. All my experiments go to prove the correctness of this statement. This has been attributed, and I think correctly, to electric influence called into operation in the preparing processes by heat and with the acid. It will be found that an *unprepared plate* requires as long again to become properly coated with iodine as does a *prepared one*; and a *pure plate*, though carefully prepared, a third longer time than a *compound one*.

It is necessary, to produce iodination readily, and to ensure the best effect from radiation, that a semi-oxidized surface be presented to the iodine. This fact will render obvious the superiority of the two metals; common observation will show, that plated goods lose their lustre much sooner than silver articles, the process of oxidation being much accelerated by the compound arrangement.

2. If an unprepared plate be iodinated and exposed to light, it darkens, and its superficial coat may be easily rubbed off, leaving a surface of exquisite lustre, somewhat darker than that which results from the nitric acid process, and more susceptible of iodination. Whether a film of oxide or iodide of silver is here produced, I am uncertain: I suspect the former*. It is, however, evident that the silver has undergone some change.

3. If a leaf of very *pure untarnished* silver be carefully spread upon card, or a piece of glass, and at once exposed to the vapour of iodine, it will be found to remain unattacked for a considerable time.

4. If a silver leaf thus spread be well burnished, it will be seen that iodine acts upon it more readily than before.

5. If we burnish half of a leaf, and tarnish a portion of both the dull and bright parts, the iodine will then attack, first, the tarnished, then the bright, and last of all the unpolished portion.

6. Spreading a leaf of silver upon a piece of copper foil, and, to render the adhesion perfect, applying a gentle heat, a surface was formed which received the iodine readily. A sheet thus prepared was perfectly iodinated in five minutes, whereas a surface of the same extent on glass required twelve minutes.

These results established in my mind most satisfactorily, the possibility of giving to paper all the properties of the silver plates. It is clearly shown, that a degree of oxidation is required on the metallic surface. From this fact, the necessity is suggested of examining the peculiarities of action manifested by iodine, on the oxides of silver produced in different ways, and their relative states of sensibility to luminous influence induced by iodination.

* See Philosophical Magazine, vol. xvi. p. 271.

To prevent circumlocution in describing the results of the inquiries into which I was led, I would explain, that when I speak of a paper being rendered sensitive, I always mean, that it becomes, after exposure to light, capable of receiving the mercurial vapour.

7. Muriated photographic papers, variously prepared, pass, more or less rapidly, through the stages of oxidation, to a perfect reduction of the metal, by the operations of light.

An examination of the effects of iodine, on all varieties of these papers, was instituted.

Any of the ordinary photographic papers allowed to darken to a full brown, become, by long exposure to iodine, of a steel-blue, or a violet colour. If exposed in this state to sunshine for a long period, their colours change from gray to a clear olive.

Now, exposure to sunshine for a minute, or to diffused daylight for from five to ten minutes, produces no *apparent* change, but mercurial vapour speedily attacks the uncovered parts, and a faithful picture is given of whatever may have been superposed, but there is a want of sufficient contrast between the lights and shadows.

8. By allowing the first darkening action to proceed until an olive coating is formed on the paper, I find, although it is not more speedily affected by the iodine, that it is more sensitive, and a better picture is formed than upon the brown paper.

The kind of preparation used, appears to have but little effect upon the results. A chloride, iodide, or bromide of silver allowed to darken, answers equally well.

There are, beside the faintness of the picture thus produced, defects which will, I fear, prevent our availing ourselves of this easy method of producing a moderately sensitive Daguerreotype paper. In the first place, the coat of oxide formed at the instant of exposure, protects the under layers of the salt, and the decomposing process proceeds irregularly; and even the longest exposure appears insufficient to remove the whole of the chlorine, which obstinately, in the form of the sub-chloride of silver, remains in the paper. This occasions the iodination to be less complete in some parts than in others, and, consequently, a variation in the photographic effect. Again, it appears, that upon the surface, long exposure effects a revival of the silver in minute points, around which the mercurial vapour is deposited in greater quantity than over the other parts of the paper.

9. My next object was the production of a perfect oxide of silver, equally diffused over every portion of the paper. In this I have encountered many very great difficulties: irregularities, almost beyond detection by other means, became of serious consequence in the delicate process I was studying.

The most effectual method I have discovered, is, first to soak the sheet in a weak solution of pure potassa, and after partially drying it, which must be done quickly, pass it through a solution of the nitrate of silver, and allow it to dry slowly in the dark. The paper is now a light brown; but by heating it over a metallic plate, or

in front of a clear fire, to a point just below that at which it would be scorched, a perfect formation of the olive oxide of silver results.

The iodine vapour requires an equally long time to produce any visible effect upon this paper, as upon those before mentioned (8. 9.). But half an hour is sufficient to render this preparation so far iodidated as is necessary, or indeed as is possible, without impairing its sensibility.

This iodidated oxide requires a strong light to yield any decided effect, and a greater heat than is directed by DAGUERRE must be applied to the mercury to bring out the impression, which is but faint at last.

10. The protoxide of silver, and some of its salts, now engaged my attention. Taking advantage of the facts pointed out by WOHLER*, I exposed papers saturated with a solution of the nitrate of silver, and dried in a cylinder which was kept hot by boiling water, to a current of very pure heated hydrogen gas. By this means I obtained a paper of a brick-red colour. This appears to be a nitrate of the protoxide of silver; by soaking this paper in rain water for some time, the free acid was removed from it, and on drying it became darker than before.

This paper is not very readily attacked by the iodine, but it is, by the exposure of an hour to a full volume of its vapour, rendered slightly sensitive.

11. By immersing a paper prepared as above (10.) in a solution of pure potassa, the salt is decomposed, and the paper on drying becomes a full black, which on being passed through steel rollers, assumes a fine lustre, resembling that given by PLUMBAGO.

This paper is more readily attacked by the iodine than the former (10.), but it is not more sensitive. In bright sunshine I have produced a tolerable copy of a leaf with its delicate vernations, but in the camera I have never succeeded as I desired, or indeed as I expected.

12. The deutoxide of silver is reduced to the metallic state by hydrogen at high temperatures. By the same arrangement as above (10.) I was enabled to get a very perfect silver paper, which in all respects was similar to the paper which is mechanically silvered (3.).

13. Having proved that iodine has the power of rendering sensitive, not only the oxides of silver, but a salt of the protoxide, it became an interesting inquiry to ascertain whether it would produce any like effect upon other salts of silver. The only one, however, I have yet discovered which admits of the desired influence, is the yellow-brown phosphate of silver. The iodine in two hours does not produce the slightest change of colour, but exposure to light and the vapour of mercury shows that the iodine imparts some sensitiveness to this salt.

14. A careful examination of the silver surfaces produced by the action of the per-phosphuretted hydrogen gas on various salts of that metal, now occupied my attention, and undividedly engaged it for a very considerable time.

* Journal de Pharm., Juillet, 1839.

My first attempts at producing, by this means, extensive surfaces, were failures; the paper generally presented a gray silver spot surrounded by a series of highly coloured rings, and an external one of a velvet black; these were of course phosphorus and silver in various proportions. Even in this state, sunshine appears to have some effect upon the papers; the inner most circles, the red and yellow, pass with tolerable quickness into different shades of olive.

By exposure to iodine the coloured rings are attacked, and changed in their characters, long before any influence is apparent on the pure silver spot, generally, but not always, assuming their complementary colours. The sensitiveness of these bands is as their position; the black exhibiting a decided action, which lessens in every ring, and is lost on the verge of the gray silver. If the silver is allowed to assume the required golden hue from the iodine, the order of sensitiveness is reversed.

15. To prevent explosions of this spontaneously inflammable gas, I have, amongst other methods, used the vapour of ether. When this has been the case, at the moment of reduction a portion of carbon appears to be separated from the ether, and, combining with the phosphorus, is deposited on the paper, forming a band of a yellow brown tint, which is sometimes found within and at others without the coloured circle, the place appearing to depend on temperature. I was at first inclined to consider this as a simple combination of phosphorus and carbon; but the sensitiveness of the band inclines me to the opinion of its being a carbo-phosphuret of silver. I should state that it stands next to black in the order of sensibility: I find the same effect is produced by dissolving the nitrate of silver, with which the paper is washed, in spirits of wine.

16. By very carefully spreading a strong solution of the nitrate of silver over a highly-calendered paper, and then exposing it to the perphosphuretted hydrogen slowly evolved from the phosphuret of lime, a very even metallic surface was formed, from the leaden colour of which it may be concluded some phosphorus had entered into combination with the silver. This paper was soon attacked by the iodine, was little less sensitive than the silvered copper, but it was scarcely possible to remove the iodine, so as to preserve the picture when complete, without portions of the surface breaking away, so slight was the adhesion between the paper and the metal.

17. By allowing the paper to absorb the silver solution, and to become nearly, but not quite dry before exposed to the gas, and the gas, which I usually form from phosphorus and solution of potassa, being liberated in large quantities, a black paper possessing in a very eminent degree all that is desired, is the result.

Unfortunately, however, although I have used every precaution, I find it impossible to prepare more than a dozen quarter-sheets without an explosion of the gas. In placing and removing the paper, atmospheric air necessarily enters the vessel, besides which, a quantity of oxygen sufficient to occasion spontaneous inflammation is set free from the nitrate of silver and the water absorbed by the papers. On one occasion I so placed and arranged some papers in a vessel as to do away with the pos-

sibility of any admission of atmospheric air; the formation of the black phosphuret of silver was going on beautifully, when the large glass vessel burst with such violence that the largest piece I could find was but the sixteenth of an inch over.

I do not at present see any way of preparing those papers with safety, and, much against my inclination, I have abandoned the use of this gas.

18. The exposure of muriated and simply nitrated photographic paper, darkened by light to the vapour of phosphorus, suggested itself. It has been noticed, that most vapours have a disposition to attack by the edges; thus it is with that of phosphorus. If the paper be suspended, the edges will present a band of silver, slightly coloured, long before the other parts exhibit any signs of having been at all acted on. The precaution, therefore, of fixing the paper in a frame and exposing its flat surface over a large quantity of phosphorus broken into small pieces, is of great importance in the preparation. When carefully prepared, this paper stands above the oxides of silver for sensibility, but infinitely below the phosphuret.

19. The vapour of sulphur was next tried, and to a great extent with success. If the paper was placed in the vapour while yet wet, the reduction was too rapid, and the continuity of the surface was broken. If allowed to dry, a more perfect surface was formed, but it was exceedingly apt to become iridescent, and every shade, after the iodine was applied, was differently sensitive. It, however, sometimes furnished a very perfect paper, capable of producing a fine photographic picture.

20. The action of sulphurous acid gas was studied with attention, but only when the paper was absolutely dry and maintained at a high temperature, could I succeed in getting any revival of the silver, which was rapidly attacked by the gas and converted into a sulphate.

21. Papers prepared with the nitrate of silver are, when plunged into a vessel containing sulphuretted hydrogen, speedily covered with sulphuret of silver. The first action of the gas is the revival of very white silver, over which a brown shade is quickly diffused, which passes into a lead colour if the paper is *moist*, or becomes variegated if it is *wet*. These papers are equal in most respects to those prepared with the phosphuretted combination.

22. If a current of sulphuretted hydrogen be *thrown upon* a paper still wet with solution of nitrate of silver, beautiful coloured rings are produced. When the gas is fully saturated with sulphur, these rings are very dark, and of the richest lustre. If in this state they are placed between the leaves of a printed volume, a perfect copy of the printing is made in twenty-four hours, the letters being white. By passing the paper through an alcoholic solution of iodine the letters become a full black. The singular nature of this fact will account for its introduction in this place*.

* On several occasions, when papers variously prepared (but not darkened) and marked and numbered with pencil at the back have been laid together, face to back, in the dark for some time, the pencil marks on some of them have been found exactly copied (in reverse) in a dark brown impression on their neighbours. This

23. By plunging a paper washed with the solution of the nitrate of silver into a very diluted volume of sulphuretted hydrogen, and transferring it from thence into pure gas, a tolerably perfect surface is generally obtained.

The continual plague of this process is, the want of perfect uniformity in the texture of the paper, which will often, in spite of every care, occasion an unequal absorption and thus mar the effect.

24. Having tried every variety of paper I could procure, and finding all more or less objectionable, I had recourse to sizes of almost every variety. The difficulty was not, however, overcome by any of them; the one which answered best was starch, which has the very singular property of altering the general appearance of that portion of the picture which is formed by the mercurial vapour when it is immersed in solutions of the muriate, or hyposulphite of soda, destroying the downy appearance, and giving it a sheeted silvery one.

25. The experience gained by preparing these sulphuretted papers on an extensive scale, enables me to point out a method by which most of the defects arising from the inequalities of the paper, and its different rates of imbibition, may be overcome.

The paper is to be first *soaked* in a weak solution of the muriate of ammonia, carefully wiped with cotton cloths, and dried slowly. It is then to be dipped in a very dilute solution of the nitrate of silver, and the small bubbles which form on its surface to be carefully removed with a camel's-hair pencil. When the paper is dried, which must be done in the dark, it is to be exposed in a closed vessel to sulphuretted hydrogen, slowly formed from the sulphuret of antimony and hydrochloric acid: in a few minutes it will darken to an iron brown. The paper must now be passed through water slightly impregnated with chlorine, or hydrochloric acid, and again dried. It must then be immersed in a solution of silver rather stronger than the first, and dried, whether in the light, or otherwise, appears of little consequence, care being taken that no shadow falls on the paper, as some difference exists between the shaded and exposed portions; but the sensitiveness changes in a singularly uncertain way from the one to the other. It is to be again subjected to sulphuration, and by careful management the process is now generally completed. If, however, the paper is not considered as sufficiently dark, it must be once more washed in the solution of silver, and again subjected to the action of sulphuretted hydrogen.

26. If the above muriated paper (25.) be allowed to remain in the sulphuretted hydrogen gas after the maximum blackness is produced, it is again whitened with some quickness. This may be accounted for in two ways; the gas may be mixed

effect is not produced by all pencils on the same paper, as a preparation of the paper, nitrate of silver over borax, seemed to succeed best.

Gold-leaf printing (the common ornamental printing on cards, &c.) may be copied on nitrated paper, by simple juxtaposition and gentle pressure for some time in the dark, which is probably owing to the copper used as alloy, as the other may be by sulphur in the pencil.—J. F. W. H.

with a portion of muriatic vapour, or a quantity of chlorine, sufficient to produce this effect, may be liberated from the preparation on the paper, to react on the sulphuret of silver.

The most elaborate directions would be quite insufficient to ensure the production of perfectly equal papers: repeated experiments alone will ensure a certainty in the result. To produce a glittering metallic surface is less difficult, but the perfection of the papers consists in having a deep black ground to contrast with the mercurial deposit. No silvering on paper can be brought to the lustre of the metallic plates, and consequently, although the revived silver may be rendered tolerably dark by using very pure sulphuretted hydrogen and a strong solution of silver, yet the contrasts are not sufficiently decided. With the black papers the picture is seen equally well in all directions, and the adhesion of the mercurial particles is closer than where a glittering surface has been presented to the action of its vapour.

27. If the paper is removed from the sulphuretted hydrogen at the moment the first white silver is revived, or still better, if the silver is revived by hydrogen gas, it may be used to produce effects like what Sir JOHN HERSCHEL designates the negative variety of photographic drawing.

After the drawing is produced in the usual method of the Daguerreotype, it is only necessary to immerse it in a warm saturated solution of common salt. The silvered portion gradually acquires a beautiful whiteness, while the parts covered by the mercury pass into a deep gray. All the fine effects producible by the original muriated photographic papers are given by this process, and the picture has the advantage of being absolutely permanent.

Method of using those Papers.

28. All the kinds of paper above-mentioned may be rendered sensitive by being exposed to the vapour of iodine, the best mode of applying which, is to spread over a thin board, the size of the sheet, a paste of iodine with spirits of wine. This board is placed in a box, and the papers being fixed in a frame about three inches above it, are iodinated in a few minutes. This plan is equally applicable to the plates.

For the sulphuretted paper I recommend another plan, which has many very great advantages. It consists simply in drawing the surface of the paper lightly over a solution thus formed: a saturated solution of any hydriodic salt is made to dissolve as much iodine as possible; and of this liquid two drachms are mingled with four ounces of water.

Care is required that one side only of the paper be wetted, which is by no means difficult to effect, the fluid is so greedily absorbed by it; all that is necessary being a broad shallow vessel to allow of the paper touching the fluid to its full width, and that it be drawn over it with a slow steady movement. When thus wetted it is to be quickly dried by a warm, but not too bright fire; of course daylight must be carefully excluded. Papers thus iodinated do not lose their sensitiveness for many days.

29. There are many inconveniences attending the use of fluid mercury, particularly to travellers; I therefore propose a plan by which this may be avoided, and the mercurialization very much facilitated. It is this: the box used for vaporization is so made as to admit of a piece of copper, rather more than half the size of the paper or plate, being placed upon the iron bottom. When required for use, the copper is rubbed over with the nitrate of mercury, washed, dried, and fixed in its place. As soon as the copper gets hot, which is very quickly, the mercury on its surface is volatilized, and the action on the photograph effected. I find this plan occupies only half the time of the original, with a capsule of mercury.

30. The drawing is now to a certain extent complete, but I have found the use of the hyposulphite of soda to remove the iodine objectionable, on the ground of its tendency to darken the mercurial deposit. A warm solution of the muriate of soda is more efficacious.

31. I have now to call particular attention to a phenomenon of a most remarkable character, opening a wide field for inquiry. The singular manner in which the mercurial vapour arranges itself on DAGUERRE's tablets has excited much attention, and given rise to numerous speculations, but even this appears to me far less curious than the following discovery.

If one of the above papers, when removed from the mercurial vapour, be dipped into a solution of the bichloride of mercury, the drawing disappears, but after a few minutes it is seen, as if by magic, unfolding itself, and gradually becoming far more beautiful and whiter than before—delicate lines, before invisible or barely seen, are now distinctly marked, and a rare and singular perfection of detail given to the drawing.

It may appear at first sight that the bichloride of mercury dissolves off the metal and deposits it again in the form of chloride (calomel). But this does not account for the fact, that if the paper has been prepared with the nitrate of silver, the mercury disappears, and the drawing vanishes, the deposit taking place only on those parts upon which light has acted but feebly, as, for instance, on the vernations of leaves, leaving those portions of surface exposed to full luminous influence without a particle of quicksilver. When the paper has been either a chloride or iodide, the effect is as above, and the thickness of the deposit is as the intensity of the light has been; consequently the semi-tints are beautifully preserved. If the drawing remains too long in the solution, the precipitate adheres to the dark parts and destroys the effect. The singularity of this operation will be more striking if the picture has been soaked for some time in a solution of the hyposulphite of soda, and then dipped into the bichloride of mercury. As the drawing disappears, a series of circles, formed of a white powder, appear to arise from the paper, generally commencing at the centre, and slowly extending over its whole surface: the powder is afterwards deposited, and the sheet is buried in the precipitate; but on taking the paper from the liquid and passing a stream of water over it, the precipitate is entirely removed from all the parts,

except the lights of the picture. To explain the rationale of this definite arrangement of a dense precipitate, is beyond my power.

32. Sir JOHN HERSCHEL has recently shown that corrosive sublimate obliterates the ordinary photographic drawings, and that they may be restored by the hyposulphite of soda. An equally singular effect is produced upon some of the papers above-mentioned. If the ordinary muriated photographic paper darkened (7. 8.) be used to procure a drawing by the process which occupies our attention, on being treated with a solution of the bichloride of mercury, the dark parts of the picture are whitened, and it of course becomes of the negative variety; but it is speedily rendered positive, or the lights and shades corrected, by the hyposulphite of soda. We have it thus in our power to produce upon the same sheet two very marked varieties of photographic drawings.

Devonport, May 5, 1840.

POSTSCRIPT.

(a.) I find the invisible photographic image, on the papers prepared by sulphuration, becomes evident without the aid of mercurial vapour, by simply soaking for some time in a solution of corrosive sublimate. The picture thus formed is extremely faint, but the fact is worthy of notice, as it may ultimately lead to the discovery of a process, by which the disengagement of the light-created picture may be effected by more simple means than at present.

(b.) If papers saturated with starch prior to being washed with the salt of silver and exposure to the sulphuretted hydrogen gas, the silver being applied on one side only, be, when completed, placed between the leaves of a printed book and subjected to some little pressure, the printing is faithfully copied off on the *unsilvered* side. It is with difficulty the letters can be made out when the paper is taken from the volume, but by immersing it in a solution of iodine they become a deep blue, verging on a black, whilst the ground remains of a yellow colour, which by the continued action of the fluid changes to a light violet. On drying, the ground becomes considerably darker, and the printing, though evident, indistinct, appearing in some positions the lightest, in others the darkest portions of the paper. These, and the facts above-mentioned, render it probable that we may eventually succeed in copying prints, &c. by mere juxtaposition.

R. H.

May 19, 1840.

XVII. Description of an Escapement for an Astronomical Clock, invented by the late Captain HENRY KATER, F.R.S. &c., drawn up from his own Memorandums by his Son EDWARD KATER, Esq. Communicated by Sir J. F. W. HERSCHEL, Bart., K.H. V.P.R.S. &c.

Received March 26,—Read April 30, 1840.

IN venturing to offer to the attention of the Royal Society the following description of an escapement for an astronomical clock, I beg to premise that I restrict myself almost entirely to the collecting and arranging of my father's own notes respecting it, written at intervals during the many years he was engaged upon it. His last improvement was made very shortly before his death, but from increasing ill health he was unable to pursue the requisite observations for verifying the accuracy of the present plan.

Owing to the numerous memorandums left by my father on this subject, I am fortunately able to give the description of the escapement nearly in his own words, with but little addition beyond some drawings which I have made to elucidate the explanations.

I regret that I have not had an opportunity of trying this escapement myself, but from the great care and attention which my father bestowed upon it, I am induced to believe that it may prove a valuable invention.

The two escapements most usually found in observatories, viz. GRAHAM's dead beat and MUDGE's escapement, were objected to by my father, on the ground of the fatal defect common to them as well as to all others hitherto invented, namely, that the impulse communicated to the pendulum is affected by any irregularity with which the impelling power is transmitted through the train.

If the number of wheels and pinions of which the train consists be taken into consideration, it was his opinion, that no excellence of workmanship can ever ensure that equality of ultimate action on the pendulum, which is the great desideratum, and which is necessary to its perfect performance.

In the dead beat escapement, the impulse is given by the teeth of the scape-wheel, pressing and sliding on inclined planes or pallets connected with the pendulum, which thus urges it in the direction of its vibration. The degree of impulse, therefore, communicated to the pendulum, will depend on the force with which the teeth of the scape-wheel press upon the inclined planes, and this will vary according as the moving power is transmitted with more or less freedom through the train.

MUDGE's escapement consists of two arms, moving on separate axes, and terminated

by inclined planes or pallets. At the top of each inclined plane is a projecting detent, on which the tooth of the scape-wheel rests, after having, by sliding along the inclined plane, raised the detent through a space equal to the height of the plane.

The pendulum, meeting a wire which projects from the arm, forces the detent from the tooth which rested upon it, carries the arm before it to a certain height, and is pressed by the arm in its descent through a space increased by the height of the inclined plane or pallet, the excess affording the impulse.

Although my father admitted that this escapement performed admirably, he still objected to it, first, because it is dependent upon the train, and consequently a greater or less pressure of the tooth of the scape-wheel upon the detent will oppose a corresponding resistance to the pendulum in unlocking; and secondly, because the beat is scarcely audible. If to remedy this, weight be added to the clock, it will then be liable to trip.

The little success with which attempts to improve the astronomical clock had been attended, my father considered might be accounted for by the circumstance, that attention had been almost exclusively paid to effecting, by means of superior workmanship, a regular transmission of the moving power through the train, instead of merely viewing the train as an assemblage of wheel-work for registering the number of vibrations made by the pendulum; whereas, he conceived that the great object was to discover a mode of communicating equal impulse to the pendulum through some principle, perfect in itself, and not dependent for its success on superior execution.

In the construction of some chronometers, this idea has been partially kept in view, especially in the REMONTOIR escapements; and in such escapements the train is employed merely to wind up a spring, which is detained in its place by means of a detent. This detent being removed by the balance, the spring is again at liberty to act and give the impulse.

The objection, however, to the REMONTOIR escapement is, that the balance has to unlock a detent, and thus the delicacy and freedom of motion of that part, the undisturbed action of which should be as much as possible preserved inviolate, is interfered with, and this, my father conceived, was the reason that chronometers with REMONTOIR escapements proved in some respects less perfect in their performance than those of the usual superior construction, in which the impulse is given directly through the train.

The pendulum of the escapement which I am about to describe merely raises a weight, and is impelled by that weight through an increased space in its descent; it neither unlocks a detent, nor has anything to do with the train; and as the weight raised and the spaces described are constant quantities, this escapement is in the strict meaning of the term one of equal impulse.

I shall now proceed to give the general description of the escapement and its mode of action, together with the precautions necessary to be observed in its construction, which I have collected from the notes left by my father, and as I wrote many of

them down from his own dictation, and frequently assisted him in many of the experiments, I can give this description as if it came from his own pen. I have added also a more minute account of its various parts, and of their size and weight, which I have lately estimated.

In Plate XI. fig. 1., *A* represents a piece of brass, which is called from its shape the anchor, to which the detents, *a* and *b*, made of thin plates of agate, are attached. The anchor is supported on an axis passing through its centre of gravity: it is 0.24 inches thick, and weighs about 4031.4 grains. The detents are regulated so as to engage at the proper depth by means of the pins *q*, *r*, having oval or eccentric heads. Two arms, *d e* and *f g*, are supported by two separate axes at *d* and *f*; and at *e* and *g*, two steel pins project at right angles to the arms, between which is the cross-piece of the pendulum, upon which these steel pins act. Two pallets, *h* and *i*, faced with agate, are attached to the arms *k v*, *l w*, and move by the flexibility of their springs at *t* and *x*, which serve merely as joints. The motion of the pallets is limited and regulated by the screws *m* and *n*, which pass through cocks attached to the arms *d e* and *f g*. Two screws, *o* and *p*, are tapped into the arms *d e* and *f g*, and pass through large holes made in the arms carrying the pallets. These screws are intended to act upon the anchor, and raise the detents.

Fig. 1. represents the situation of the different parts of the escapement when the pendulum is descending in the direction indicated by the arrow. On the one side, a tooth of the scape-wheel having elevated the pallet *i* through a space equal to the height of its inclined plane, is resting on its summit. The anchor is pressed upon by the screw *p*, with the weight of the arm *f g*, so as to render any tripping impossible, and the scape-wheel is locked by the detent *a*. As the pendulum advances, the cross-piece meets the projecting wire at *g*, carries forward the arm *f g*, frees the anchor from the pressure of the screw *p*, leaving it free to be acted upon on the other side, and ultimately raises the pallet *i*, by means of the screw *n* meeting its arm. By the time this has been effected, the bottom of the inclined plane of the pallet *h* meets a tooth, and the screw *o* is all but in contact with the anchor. The weight of the pallet *h* is thus taken off from the pendulum, whilst the weight of the arm *d e* continues for a moment to impel it, till the screw comes in contact with the anchor. At this instant a sudden stop, during a small fraction of a second, takes place in the motion of the arm, in consequence of the vis inertie arising from the great weight of the anchor. The pendulum, therefore, is no longer rested upon, but having quitted the wire at *e*, the weight of the arm *d e* overcomes the inertia of the anchor, the detent *b* is pressed down, and the scape-wheel being freed, raises the pallet *h*, and rests on the summit by another tooth having come in contact with the detent *b*.

Such is the action of this escapement. Its perfection depends on the action of the arm upon the pendulum being at once checked, and terminated by the vis inertie of the anchor, in which case the pendulum quits it, leaving to the arm the work of

unlocking the detent. To calculate with accuracy the time the arm is detained is perhaps impossible, but a sufficient approximation to this may, and has been made, to demonstrate that it cannot overtake the pendulum during the unlocking of the scape-wheel, which is all that is necessary.

This escapement, therefore, is demonstrably one of equal impulse, the impelling power being purely the pressure of the pallet in its descent, through a space equal to the height of its inclined plane.

I shall now give the directions which my father considered might be necessary for the construction of the escapement.

The various parts which compose the escapement are attached to a piece of plate brass, which is afterwards screwed to the back plate of the clock, in such a position as to place the detents in their proper situation with respect to the scape-wheel. The anchor, as already mentioned, 0.24 inch thick, and weighing 4031.4 grains, is made thus heavy in order that its inertia may be sufficient to arrest the descent of the impelling arm, so that, during the raising of the detent, the arm cannot possibly overtake the pendulum. The form of the anchor is sufficiently indicated by the plate. The axis is of steel, and turned with shoulders: it is made to pass through the centre of gravity of the anchor by filing it away when necessary, after the detents are attached to it. The detents are small plates of agate, properly bevelled at the extremity, and fixed in their places by shell-lac. The distance between the faces comprise eight and a half teeth of the scape-wheel, and the chord or distance between the extremities of the detents may be found by multiplying the diameter of the scape-wheel by 0.777. If lines ya and $y b$ be drawn from the axis of the anchor to the extremity of each detent, and the faces of the detents be produced to a' and b' , the angle $y b b'$ should be rather less, and the angle $y a a'$ should be rather more than a right angle; perhaps a difference of five degrees from a right angle may be quite sufficient. The object in this is to give a tendency to the scape-wheel to draw the detents downwards.

The anchor is screwed in its place by means of a cock, which receives one end of the axis, the other end passing into the brass plate.

The distance of the axis of the anchor above the centre of the scape-wheel is found by multiplying the diameter of the scape-wheel by 0.64.

The steel stops, q and r , are rivetted into the brass plate, but not so firmly but that they may be turned by a screw-driver. The upper part of these stops is made either oval or eccentric. They serve to regulate the depth to which the detents are to engage the teeth of the scape-wheel.

The arms $d e$ and $f g$ are of plate brass. The length of each arm, from the point where it is attached to the axis, in a straight line drawn to the lower end where the steel wire projects, is about 4.8 inches. Each of these arms is attached to an axis by a screw and steady pin, and from the lower end of each arm, a piece of steel wire projects for the purpose of impelling the pendulum.

The axis to which the arm is attached is represented in Plate XII. fig. 2. It is merely a piece of steel wire 3·1 inches long (to prevent shake), having a small plate of brass brazed to it at A, to which the arm is screwed.

The piece for receiving the two axes is represented by B C, fig. 3. It is firmly fastened to the brass plate A, which carries the escapement, by means of screws passing through the piece D, which forms a part of it. The holes for receiving the axes are drilled quite through the ends B and C, and caps of plane brass, carrying planes of agate, are screwed to the ends, and keep the axes in their places, preventing any longitudinal motion. The axes are placed at one diameter of the scape-wheel above the centre.

The pallets are of brass and faced with agate; they are carried by arms terminating in very flexible springs, which serve merely as hinges, and these springs are attached to the arms *d e* and *f g*, Plate XI. fig. 1.; at *v* and *w* the arms project a little beyond the pallets, and rest upon the screws *m* and *n*, which pass through cocks fixed to the arms *d e* and *f g*. The length of the arms carrying the pallets is such, that a tooth of the scape-wheel may rest at the bottom of the one pallet, when another tooth is at the summit of the opposite pallet.

The pallets should be made light, and if it be found necessary to increase the impelling power, it may be done by fixing a pin in the arm carrying the pallet, which pin must pass freely through the impelling arm, and being formed with a shoulder, may be loaded by lodging upon it such small weights as may be necessary.

The steel pins *o* and *p* are tapped into the arms *d e* and *f g*, and pass freely through holes in the arms carrying the pallets. Their position is such, as to allow of their acting upon the anchor at the stops *q* and *r*; all the screws act upon small pieces of agate, let into the brass-work, and they are furnished with nuts to prevent any shake or motion after the adjustments are completed.

The pendulum which is employed with this escapement has a glass cylinder, which holds the mercury used for the compensation, upon the surface of which a circular piece of plate glass floats, to prevent any sudden change of curvature which might arise from the adhesion of the mercury to the sides of the vessel, upon a change of temperature. This cylinder has a projecting rim at top which admits of its being lodged in a sort of iron hoop, formed like a box, with an aperture in the bottom through which the glass cylinder passes, and into which it is cemented. An iron cover screws into this box, having a projecting tube in the centre, to receive a glass tube, which is the rod of the pendulum. The pendulum is suspended by a spring in the usual manner, from a stout cock firmly screwed to the back of the clock-case, and in which all shake is precluded by the pressure of a screw passing through the side of the cock.

The pendulum has a sliding weight on its rod, for the purpose of approximate adjustment, and the final adjustment is effected by small weights placed upon the iron cover.

The cross-piece Z of the pendulum is represented in fig. 1. In consequence of its sides being bevelled, its acting part may be increased by raising it on the rod of the pendulum. The cock which carries the pendulum itself is supported upon a cast-iron bracket, firmly fastened to the clock-case.

The adjustments of the escapement are made in the following manner:

First, the brass plate carrying the whole must be screwed to the back plate of the clock, so that neither of the detents being pressed down, they may first enter within the teeth of the scape-wheel. By this arrangement it will be impossible for the scape-wheel to turn round without encountering one or other of the detents.

The next is by means of the executive stops, to adjust the depth, to which the detents shall engage the teeth of the scape-wheel, and this should not be more than is necessary for secure locking.

A piece of card of the form represented in Plate XII. fig. 4. must be prepared, A B being equal to the upper, or least width of the cross-piece of the pendulum.

The clock must be placed upon a level support, and the card lodged upon the impelling wires of the escapement; a tooth must be made to press against the detents, and the pallet which is on the same side with this detent should be adjusted, by means of its approximate screw, *m* or *n*, so that it shall be quite clear of the tooth of the scape-wheel. The other detent must now engage a tooth, and its pallet be adjusted in like manner. Lastly, the card paper is removed, and the anchor being kept in contact with one of its stops, a tooth pressing against the detent, the pallet on the opposite side will rest with the bottom of its inclined plane upon a tooth of the scape-wheel. The screw *o* or *p*, which is on the same side as this pallet, must now be advanced, until by acting upon the anchor, it just causes the pallet to clear the tooth. This is too much, and the screw must now be withdrawn a little till it is found by trial, that when the bottom of the inclined plane of the pallet meets the tooth of the scape-wheel, the screw is just short of the anchor. The same process must be gone through on the other side, and the adjustments of the escapement will then be completed.

The weight to the clock must be adjusted by trial, so that the scape-wheel shall raise the pallets promptly, but not press with unnecessary force upon the detents.

The plan for fastening the clock-case to the wall is by a single screw passing through its back, a little above the cock which carries the pendulum.

Another similar screw passes through the case into the wall, a little below the ball of the pendulum, and is furnished with a washer. A slit is here cut in the clock-case, at the back, parallel to the horizon, and the clock is put into beat by moving the case as much as may be necessary about the upper screw as a centre, and the clock-case is then firmly fixed by tightening the lower screw. It is scarcely necessary to say, that the clock-case should not touch the floor.

My father never made use of oil in this escapement, as it might, by becoming glutinous, occasion irregular action.

XVIII. *On the Constitution of the Resins. Part IV.* By JAMES F. W. JOHNSTON, Esq.
M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham.

Received March 16,—Read April 9, 1840.

IX. *Resin of Scammony.*

WHEN the purest scammony of commerce is digested in cold alcohol, a pale yellow solution is obtained, which, on evaporation, gives a pale yellow, opaque, hard, and friable resin. Heated to 300° FAHR. this resin melts, becomes transparent, and emits a peculiar odour. By the action of the alcohol the crude scammony is very little diminished in bulk.

A. After heating forty-eight hours at 250° FAHR. the resin obtained from the alcoholic solution was still in the state of powder, and 12·69 grs. gave $\bar{C}$ = 25·74, and $\bar{H}$ = 9·06 grs.

B. Heated for twelve hours at a temperature at which it cohered, 11·56 grs. gave $\bar{C}$ = 23·35, and $\bar{H}$ = 8·162 grs.

C. Of a third portion fused and kept in a state of quiet fusion for several hours, 11·98 grs. gave $\bar{C}$ = 23·75, and $\bar{H}$ = 8·31.

D. Of a fourth portion fused at 350° FAHR. 9·36 grs. gave $\bar{C}$ = 18·675, and $\bar{H}$ = 6·434 grains.

These results are equivalent to

A. Heated 48 hours at 250° FAHR.	B. Heated 12 hours at 260° +.	C. Fused for several hours.	D. Fused at 350° FAHR.
Carbon 56·08	55·85	54·82	55·17
Hydrogen 7·93	7·84	7·70	7·63
Oxygen 35·99	36·31	37·48	37·20
100	100	100	100

I consider the portion B. to represent most nearly the normal state of the resin, and this agrees very closely with the formula $C_{40} H_{33} O_{20}$, which gives

		Per cent.
40 Carbon	= 3057·500	55·92
33 Hydrogen	= 411·826	7·53
20 Oxygen	= 2000·000	36·55
	5469·326	100

The results C. and D. show that, by further heating, this resin loses both carbon and hydrogen, probably from the disengagement of a volatile substance containing less

oxygen than the resin itself. Nearly all the resins when heated to incipient decomposition give off more or less of a volatile oil, but in general the per centage of carbon is increased by such decomposition.

This resin is remarkable for containing the largest quantity of oxygen of any resin hitherto analysed. In this respect it exceeds even the resin of jalap, to which, as the subsequent section shows, it has so much analogy in constitution, and which it resembles also in its action on the system, and in the genus of plants (*convolvulus*) from which it is derived.

X. Resin of Jalap.

The resin of jalap is stated by chemical writers, chiefly, I believe, on the authority of CADET DE GASSICOURT*, to consist of two resins, of which only one is soluble in ether, though both are extracted from the root by alcohol. In this statement, however, there is an error, the source of which will presently appear.

I was induced to turn my attention to this resin in connection with that of Scammony, of which the analysis is above given, in consequence of a statement of GOBEL that this resin contains more oxygen than any other. He found it to consist of carbon 36.62, hydrogen 9.47, and oxygen 53.91†. This result, however, is very wide of the truth, and though jalap resin does contain a large per centage of oxygen, it is inferior in this respect to the resin of scammony.

I. The jalap resin of the shops, in lumps of a dark green colour, when digested in ether, gives a dark brown solution, and with the exception of a small quantity of impurities, dissolves entirely. When evaporated, this solution yields a brown resin, emitting, while fused, the distinct and nearly unmixed odour of common colophony. As I had every reason to believe that in this state it is largely adulterated, I did not subject the resin thus obtained to any further examination.

II. An ounce of powdered jalap was digested in alcohol, the brown solution evaporated to dryness, and the dry resinous mass treated with ether. A considerable portion of the mass was taken up by the ether, and alcohol dissolved nearly all that was left. This agrees with the statement of GASSICOURT, who says that of the resin obtained by evaporating the alcoholic solution, ether dissolves $\frac{3}{10}$ ths, leaving undissolved a second resin to the amount of $\frac{1}{10}$ ths of the entire weight.

III. As the purity of powdered jalap is not to be depended upon, half a pound of the roots was sliced and digested in cold alcohol of the shops, for three weeks, and the solution evaporated. A dark brown mass was obtained, which, after heating to 150° FAHR. for several days, refused to dry up and harden. It presented the appearance, and when warm had the consistence and something of the smell of treacle. It had also a sweetish taste mixed with that of jalap, and when set aside in the cold speedily began to deliquesce.

This mass was treated with boiling water, which dissolved at least two-thirds of

* Handbuch der Chemie, von LEOPOLD GMELIN, ii. p. 569; and THOMSON'S Organic Chemistry, p. 540.

† Dr. TODD THOMSON'S Materia Medica, ii. p. 290, 1833.

the whole, forming a dark brown solution, while the undissolved residue was entirely soluble in ether. The alcoholic extract of jalap, therefore, contains only one resin, which is soluble in ether, two-thirds or upwards of the whole consisting of one or more non-resinous substances soluble in boiling water. It is that portion of these non-resinous substances which ether does not take up, that has hitherto been considered as the second resin of jalap. This explanation reconciles my results with those of GASSICOURT, as given in Dr. THOMSON'S Organic Chemistry; but LEOPOLD GMELIN states not merely that the alcoholic extract, but that this extract *after boiling in water* consists of two resins, one soluble and one insoluble in ether. I am inclined to think, however, that, in transcribing his experiments, GMELIN has written what GASSICOURT ought to have done rather than what he did.

The solution of the resin in ether was evaporated and heated at 230° FAHR. till it became dry and solid. It was then reduced to powder and heated for several days to 200° FAHR.

A. 12.75 grs. gave $\ddot{C}$ = 26.19, and $\dot{H}$ = 9.467 grs.

Of another portion dried in a thin film,

B. 12.22 grs. gave $\dot{H}$ = 8.973, the carbonic acid being lost.

C. 10.49 grs. gave $\ddot{C}$ = 21.79, and $\dot{H}$ = 8.107 grs.

D. 9.328 grs. gave $\ddot{C}$ = 19.47, and $\dot{H}$ = 7.056 grs.

These are equivalent to

	A.	B.	C.	D.
Carbon	56.80		57.44	57.71
Hydrogen	8.24	8.16	8.58	8.40
Oxygen	34.96		34.08	33.89
	100		100	100

I believe that the deficiency of carbon and of hydrogen in the analyses A. and B. is due to the employment of sand of too high a temperature while pumping out the moisture, and that C. and D. represent more nearly the true constitution of the resin. These agree with the formula $C_{40}H_{34}O_{18}$, which gives

		Per cent.
40 Carbon	= 3057.480	57.88
34 Hydrogen	= 424.306	8.03
18 Oxygen	= 1800.000	34.09
	5281.786	100

This constitution for the resin of jalap being remarkable not merely for the great number of equivalents of oxygen it indicates, but also as presenting the only example we have yet met with (with the exception of the resin of scammony) in which the number of equivalents of hydrogen is decidedly greater than thirty-two, I was anxious to submit it to still further verification: I therefore distilled off the greater portion of the ether from the ethereal solution, and digested the resin a second time

in repeated portions of hot water, by which so much was taken up as to give a yellow solution. The water being poured off, the resin was dissolved in alcohol, and a portion of the filtered alcoholic solution evaporated in a thin film, and heated for sixteen hours at 250° FAHR. As before, it had become perfectly dry and brittle, but did not fuse. This resin, however, after evaporation, remains tough for a long time, and does not become friable till after being heated for several hours.

12.36 grs. gave $\ddot{C} = 25.625$, and $\dot{H} = 9.283$, or per cent.,

Carbon	57.34
Hydrogen	8.33
Oxygen	34.34
	100

This result agrees so closely with those previously obtained, that we may consider the presence of thirty-four equivalents of hydrogen in the formula for this resin to be as certainly determined, as we can expect it to be, by the analysis of the uncombined resin, according to our present methods.

XI. Resin of Labdanum.

The resin of labdanum is said to be obtained from the *Cystus Creticus*, a native of Syria and of the Grecian Archipelago. It occurs in commerce in the form of black masses, more or less soft and tenacious. Alcohol rarely dissolves more than one-fourth of the whole mass; the solution has a dark-brown colour, a bitter taste, and gives on evaporation a dark-brown transparent resin. This resin has a peculiar, not very unpleasant odour; having, when the resin is hot and melted, a slight resemblance to that of colophony*.

1. A portion of the solution in cold alcohol (0.83) was evaporated at a gentle heat in a thin film, and afterwards heated for six hours to 212° FAHR. When cold the resin was brittle, but the fragments readily cohered when the mass was broken up.

6.635 grs. gave $\ddot{C} = 17.1$, and $\dot{H} = 5.83$ grs.

2. A second portion was evaporated and kept at a temperature of 150° FAHR. for thirty-six hours, and afterwards for four hours at 212° FAHR.

8.115 grs. gave $\ddot{C} = 21.01$, and $\dot{H} = 7.185$ grs.

These results give per cent.,

	1.	2.
Carbon	71.26	71.58
Hydrogen	9.76	9.82
Oxygen	18.98	18.60
	100	100

* The odour of colophony is that which is generally understood by the term resinous.

The formula $C_{40}H_{33}O_3$ gives

		Per cent.
40 Carbon	= 3057.440	71.62
33 Hydrogen	= 411.827	9.64
8 Oxygen	= 800.000	18.74
	4269.267	100.

3. The resin in the state in which it had been analysed, as above, was boiled in water, which became slightly coloured, and acquired a bitter taste.

It was then dried by prolonged heating at 212° FAHR., when

5.93 grs. gave $\ddot{C}$ = 15.97, and $\dot{H}$ = 5.34, or per cent.,

	3.	
Carbon	73.99	40 atoms.
Hydrogen	10.00	33.1 atoms.
Oxygen	16.01	7.05 atoms.
	100	

4. This remarkable disagreement with the previous results induced me to boil in repeated portions of water, a second quantity of the labdanum of commerce, and after drying, to digest it in alcohol. The water acquired a brownish colour, and an intensely bitter taste. A portion of the alcoholic solution was evaporated and heated, as before, in a thin film.

8.385 grs. gave $\ddot{C}$ = 22.205, and $\dot{H}$ = 7.57 grs.

5. Of the resin thus analysed (4.) the remainder was again boiled in water. The first portion of water was not coloured, but acquired a very bitter taste; in the second portion employed, the taste was scarcely perceptible. Dried by heating for thirty-six hours at 180° FAHR., it was darker coloured than the resin first analysed, and when hot had a slight odour resembling ginger.

7.01 grs. gave $\ddot{C}$ = 18.56, and $\dot{H}$ = 6.37.

These two results are almost identical, giving per cent.,

	4.	5.	$C_{40}H_{33}O_3$, gives
Carbon	73.24	73.16	73.38
Hydrogen	10.00	10.01	9.88
Oxygen	16.84	16.83	16.74
	100	100	100

In the portion 3, therefore, the carbon is in excess to the amount of 0.6 per cent., either from an error of experiment, or from the presence of some impurity in the portion analysed, while the identity in constitution of the portions 4 and 5, shows either that the bitterness imparted to the water by boiling over specimen 4, was due to the solution of the resin itself, or that the quantity of the bitter substance it contained was too small to affect the results of analysis in any sensible degree.

6. It appears then that the resin obtained by digesting the crude labdanum of commerce in cold alcohol (0.83), is represented by $C_{40}H_{33}O_8$, while that obtained by the same means from the crude resin previously boiled in water = $C_{40}H_{33}O_7$. Is this difference owing to a species of transformation of the resin, or to the extraction by the water of a substance soluble both in water and alcohol?

To determine this point, I evaporated the bitter aqueous solutions obtained respectively by boiling the crude labdanum in water, and the substance extracted directly by alcohol from the crude resin. In both cases a small quantity of bitter extractive matter was left, which gradually attracted moisture from the air, but which was not subjected to any further examination. The presence of this substance had caused the difference between the results of the two series of analyses, and the close accordance of the first series with the formula $C_{40}H_{33}O_8$ is probably only accidental.

The pure resin of labdanum, therefore, may be considered as represented in constitution by the *irrational* formula $C_{40}H_{33}O_7$.

XII. *Berengela Resin.*

Under the name of Berengela resin or Berengelite*, I some time ago published a

* The specimens of the substance for which I propose the name of Berengelite, were given to me by my friend Mr. FAYE, of Whitley House, near North Shields, and were obtained by him during his residence in South America. Of the circumstances under which it occurs, Mr. FAYE thus writes to me:—

"Of the resin or asphaltum from South America, I can unfortunately give you but a very imperfect account. I one day found in the yard of the Custom-house at Arica, a large convoy of llamas loaded with it, and all the information I could obtain from the men having charge of it was, that they brought it from St. Juan de Berengela, about 100 miles from Arica; that it was found in very large quantities, and formed, according to their description, something like a lake resembling the pitch lake of Trinidad. It is extensively used for paying boats and vessels at Arica, and, I believe, on the whole coast of Peru."

This substance is hard, brittle, may be scratched by the nail, has a resinous fracture and lustre, is of a dark-brown colour, with a tinge of green, but gives a yellow powder. The external appearance of the masses, as they were brought home, appears to indicate that the whole had formerly been in a softer state so as to yield easily to compression. It is insoluble in water, but dissolves readily and in large quantity in cold alcohol or ether, giving brown solutions. A small residue of earthy impurities is left. By evaporating the alcoholic solution, the resin is obtained of greater transparency, transmitting light of a bright-red colour, fusing easily on the water-bath, and remaining soft and unctuous at the ordinary temperature of the atmosphere. It gradually recovers its brittleness, but after the lapse of three or four months it is still soft, and adheres in some measure to the fingers. This property appears to be possessed by many other resinous substances, and explains the semifused appearance of the imported masses.

It has a peculiar, unpleasant, resinous odour. After fusion for some time at 212° FARR., the unpleasant odour disappears, and is succeeded by an agreeable fragrance. On cooling again, it assumes, after some time, its original smell. When chewed in the mouth, it imparts a slight sensation of bitterness; but the alcoholic solution has a disagreeable very bitter taste.

Like most other resins, it is nearly insoluble in a concentrated solution of caustic potash. Boiled in a more dilute alkali it gives a yellow solution, from which the resin is again precipitated by acids. The alcoholic solution gives with a similar solution of acetate of lead, a copious yellow precipitate. It is, therefore, an acid resin. Its alcoholic solution is rendered milky by liquid ammonia, and passes milky through the filter.—London and Edinburgh Journal of Science, Third Series, vol. xiv. p. 89.

description of a substance, said to occur in large quantities as a mineral deposit at San Juan de Berengela, in South America. This fossil body is a true resin of a brown colour, giving with cold alcohol a brown solution, having a peculiar unpleasant odour, and a disagreeable exceedingly bitter taste.

In the same paper I inserted also two analyses of this substance, which gave per cent.,

	1.	2.	The formula $C_{40}H_{31}O_7$ gives	The formula $C_{41}H_{31}O_7$ gives
Carbon	72.47	72.34	72.04	72.53
Hydrogen	9.20	9.36	9.12	8.93
Oxygen	18.33	18.30	18.84	18.54
	100	100	100	100

The analytical results, when compared with the calculated numbers, show an excess of carbon above what is required by the formula containing C_{40} . Being, at the time when these analyses were made, unaware of the apparently universal prevalence of this quantity C_{40} , in the formulæ for the resins, which the present investigation seems to exhibit, I was by this excess led to adopt in preference the second formula containing C_{41} . On deducing for the resin of labdanum, however, as shown in the preceding section, a formula approaching very closely to that previously assigned to the Berengela resin, I was induced to return to the latter substance, and by a repetition of the analyses to test my previous results.

1. A small portion of the alcoholic solution was therefore evaporated, and the resin in the form of a thin film kept at a temperature of 150° FAHR. for twelve hours, and afterwards at 212° for two hours. The resin when cold was brittle, but the particles cohered slightly after standing for some time. Burned in the air it left 0.20 per cent. of brown ash.

A. 10.3 grs. gave $\bar{C} = 27.26$, and $\bar{H} = 9.41$ grs.

B. 8.17 grs. gave $\bar{H} = 9.45$ grs., or per cent.,

	A.	B.	
Carbon	73.16		40 atoms
Hydrogen	9.43	9.45	31.6 atoms
Oxygen	17.41		7.3 atoms.
	100		

2. In the result A. the carbon is still more in excess than in the previously published analyses, and as the number of atoms seemed to indicate the formula $C_{40}H_{31}O_7$, I evaporated another portion, and exposed it in a still thinner film for twenty hours to a temperature, until the last two hours, not exceeding 200° FAHR. The resin thus obtained retained its natural pale colour and peculiar odour, melted at 212° FAHR., was brittle when cold, and when broken up its particles showed little tendency to cohere.

6.667 grs. (6.654 grs. pure resin) gave $\bar{C} = 17.8$, and $\bar{H} = 5.62$ grains.

3. In order to ascertain the effect of a still more protracted heating, a further portion of the solution was evaporated in a thin film, and kept at 200° FAHR. for sixteen hours. The heating appeared in this instance to have produced incipient decomposition, the resin having acquired a slightly darker colour than the portions previously analysed.

In this state 6.865 grs. (6.852 grs. pure resin) gave $\ddot{C} = 18.4$, and $\dot{H} = 5.81$ grs.

The three results above obtained give respectively,

1. 12 hours at 150° .	2. 20 hours at 200° .	3. 16 hours at 220° ?	$C_{40} H_{21} O_7$ gives	$C_{40} H_{30} O_7$ gives
Carbon 73.16	73.98	74.25	73.63	74.00
Hydrogen 9.43	9.39	9.42	9.33	9.06
Oxygen 17.41	16.63	16.33	17.04	16.94
100	100	100	100	100

From the appearances presented during the prolonged heating, I am inclined to consider the resin of 2 to have been nearly in the normal state, and that the portion 3 had been heated too long. The chief difficulty is in regard to the hydrogen, as considerable pains were taken in exhausting the moisture from the combustion tube. Considering, however, the comparatively low temperature at which the exhaustion must be performed, in order to prevent loss, in the case of a resin which melts so easily as the present, I am inclined to adopt the formula containing H_{30} as the safer of the two.

There is still therefore a relation between the Berengela and labdanum resins, the former being represented by $C_{40} H_{30} O_7$, and the latter by $C_{40} H_{33} O_7$.

XIII. Resin of Retin-Asphalt.

Having thus succeeded in bringing the Berengela resin within the dominion of our general formula containing C_{40} , I became desirous of ascertaining how far my present experience of the mode of obtaining the several resins in the normal state, might enable me to deduce for the resin of *Retin-Asphalt* a formula which would be included in the same general expression.

This resin is extracted by alcohol or ether from the mineral retin-asphalt of Bovey, of which it constitutes about sixty per cent. Evaporated at 212° the solution affords a light brown unfused resin, which begins to melt at 250° FAHR., is fluid at 300° , and at a temperature not exceeding that at which it becomes fluid, gradually decomposes. It is sparingly soluble in cold alcohol, more largely in boiling alcohol, from which it is partially precipitated on cooling. Ether dissolves it more easily and in greater quantity, giving a dark brown solution.

On a former occasion I published* two analyses of this resin, from which I deduced the formula $C_{21} H_{14} O_3$. Into this formula the constant C_{40} does not enter, as the analyses were made before the commencement of the present investigation had taught

* London and Edinburgh Journal of Science, Third Series, vol. xii. p. 561.

me, either that this constant was to be looked for in the expression for a resinous substance, or the precautions necessary to be adopted in the extraction and drying of the resins themselves.

The following analyses not only rectify the formula, but show also the cause to which the deduction of an erroneous formula from the previous analyses is to be ascribed.

Resin-asphalt was treated with three successive portions of alcohol, being boiled with the last portion till everything soluble appeared to be taken up.

The resin left by evaporating each of these three portions in a thin film, and heating it at 200° FAHR. for twelve hours, was analysed separately. It was in the state of a light brown powder, or of a dark brown film.

Of one of these portions when burned in the air,

5.774 grs. left 0.04 grs. of gray ash = 0.7 per cent.

Of another 2.417 grs. left 0.021 grs. = 0.86 per cent., giving as a mean 0.78 per cent. of earthy matter in the resin after solution in the alcohol,

A. of the first portion 5.78 grs. (5.735 grs. pure resin) gave

$\bar{C}$ = 15.74, and $\bar{H}$ = 4.571 grs.

B. Of the second 7.624 grs. (7.565 grs. pure resin) gave

$\bar{C}$ = 20.865, and $\bar{H}$ = 5.995 grs.

C. Of the third 5.88 grs. (5.834 grs. pure resin) gave

$\bar{C}$ = 16.01, and $\bar{H}$ = 4.56 grs.

D. Of a mixture of these, heated till the resin began to melt and cohere, being when cold very dark brown and porous, 7.13 grs. (7.074 grs. pure resin) gave

$\bar{C}$ = 19.51, and $\bar{H}$ = 5.445 grs.

E. Of the same fused at the lowest possible temperature for three hours, 7.805 grs. (7.744 grs. pure resin) gave

$\bar{C}$ = 21.87, and $\bar{H}$ = 6.063 grs.

These results gave for the various portions the following constitution per cent.:

Dried for twelve hours at 200° FAHR.			Afterwards heated to incipient fusion. D.	Kept at melting point for three hours. E.
A.	B.	C.		
Carbon 75.89	76.26	75.88	76.26	78.08
Hydrogen 8.85	8.80	8.68	8.55	8.70
Oxygen 15.26	14.94	15.44	15.19	13.22
100	100	100	100	100

The formula $C_{40} H_{27} O_6$, gives

40 Carbon	=	3057.48	Per cent. 76.53
27 Hydrogen	=	336.95	8.44
6 Oxygen	=	600.00	15.00
		3994.43	100

With this formula, the results of the first four analyses are accordant within the limits of the errors of manipulation. In the fifth analysis there is a large excess of carbon, obviously due to decomposition caused by the prolonged fusion.

The analyses previously published gave the following results:

After prolonged heating at 212° FAHR.	After fusion at 300° FAHR.
Carbon 76.86	77.41
Hydrogen 8.75	8.51
Oxygen 14.39	14.08
100	100

In both of these the carbon is in excess, though in neither is the excess so great as in the fifth analysis above given. It is, however, to be ascribed to the same cause, namely, to partial decomposition, though not carried so far.

From the above experiments, therefore, it appears,

1. That this resin, like many others we have examined, may be perfectly dried by heating at 200° FAHR. in the state of a thin film without being melted.
2. That when thus dried it may be represented by $C_{40} H_{27} O_6$; and
3. That when fused it rapidly decomposes, the per centage of carbon increasing, while that of hydrogen remains nearly stationary. The analysis E. gave

Carbon 78.08	$C_{40} H_{27} O_6$ gives
Hydrogen 8.70	78.51
Oxygen 13.22	8.65
100	12.84
	100

So that by prolonged heating at the melting point the formula $C_{40} H_{27} O_6$ gradually approximates to $C_{40} H_{27} O_5$, which, as will appear in a subsequent part of this paper, is identical with the change which heat produces on some other resins, as the resin of assafoetida.

4. *Salts of this resin.*—In the paper to which I have already referred I have shown that an alcoholic solution of this resin precipitates similar solutions of nitrate of silver and of acetate of lead. The salt of silver appears to be represented by $2 Ag O + (C_{40} H_{27} O_6)$.

XIV. Ammoniac Resin.

I. When the ammoniac resin of the shops is digested in cold alcohol, it undergoes little alteration in bulk, but a pale yellow solution is obtained, which on evaporation in a thin film at 150° FAHR. gives a transparent nearly colourless resin, having the characteristic odour of the natural product. Heated to 212° FAHR. for some time, the resin assumes a yellow colour, which gradually deepens, while at the same time the peculiar odour becomes less intense. After heating for forty-eight hours at 180° FAHR., and afterwards for several hours at 212° in a thin film,

A. 7.045 grs. gave $\bar{C}$ = 18.29, and $\bar{H}$ = 4.79 grs.

B. 6.76 grs. gave $\bar{C}$ = 17.62, and $\bar{H}$ = 4.645 grs.

These give per cent.,

	A.	B.
Carbon	71.78	72.07
Hydrogen	7.55	7.63
Oxygen	20.67	20.30
	100	100

The formula $C_{40} H_{25} O_9$, gives

		Per cent.
40 Carbon	= 3057.48	71.61
25 Hydrogen	= 311.99	7.30
9 Oxygen	= 900.00	21.09
	4269.47	100

which agrees so closely with the experimental results, that we are justified in adopting it as the probable formula for the resin. The two portions analysed exhibit a slight excess of carbon, which may be attributed to the too prolonged action of the heat. This is rendered more probable by the following analysis.

II. A portion of the resin, dried as above, was heated in a shallow platinum capsule over the lamp to a temperature of about 270° FAHR. for some hours, till it had almost entirely lost its characteristic odour. No frothing took place, nor were any visible fumes given off; it remained in quiet fusion, gradually assuming a greater consistence, and becoming of a darker shade of colour. In this state

A. 5.76 grs. gave $\bar{C}$ = 15.2, and $\bar{H}$ = 3.91 grs.

B. 6.98 grs. gave $\bar{C}$ = 18.37, and $\bar{H}$ = 4.67 grs.

or per cent.,

	A.	B.
Carbon	72.97	72.77
Hydrogen	7.55	7.43
Oxygen	19.48	19.80
	100	100

These results show that by a heat of 270° + this resin is gradually decomposed, the volatile matter which flies off containing more oxygen in proportion to the hydrogen than exists in the resin itself, while in some others belonging to the same natural group, as in the lump dragon's blood, the contrary is the case.

Thus deducting 0.23 from the hydrogen of analysis B. for hygrometric moisture, it becomes

Carbon	72.77	40 atoms
Hydrogen	7.20	24.24 atoms, and loss = 0.76 atoms
Oxygen	20.03	8.41 atoms, and loss = 0.59 atoms
	100	

the loss of the hydrogen being to that of the oxygen as 5 : 4, while in the resin they exist in the proportion of 8.3 to 3.

This resin is easily fusible, and like the Berengela and assafoetida resins, runs into a mass in the bottle in which it is kept. The alcoholic solution gives, with a similar solution of acetate of lead, a white precipitate, but I have not as yet analysed any of its salts.

XV. *Resin of Opoponax.*

The green resin of opoponax, treated with common alcohol, gives a pale brownish-red solution, from which, by evaporation, a transparent brown resin is obtained having a peculiar odour, fusing readily at 212° FAHR.; and after being kept at that temperature for a short time, becoming brittle when cold. The residue from the natural resin, after being treated with alcohol, gives with boiling water a solution which passes milky through the filter. Both solutions have a bitter taste, accompanied by a peculiar flavour. The matter which remains insoluble in alcohol or water consists chiefly of woody fragments, and is nearly equal in bulk to the natural gum resin originally experimented upon.

The resin extracted by alcohol is decomposed by a comparatively low temperature, and requires therefore to be treated with considerable care, when prepared for the purpose of analysis.

This is shown by the following experiments.

1. A small portion of the alcoholic solution was evaporated at a gentle heat, which, when the resin was nearly free from alcohol, was raised to 212° FAHR. It was kept at this temperature for two hours, but from the inclination of the shallow vessel a considerable portion of the resin (the whole not exceeding 10 grs.) had run together into a mass. On cooling, this latter portion did not harden. The brittle portion was scraped off the dish, and burned with oxide of copper.

7.5 grs. gave $\bar{C} = 17.14$, and $\bar{H} = 4.52$ grs.

2. A second portion of the alcoholic solution was evaporated at 150° FAHR., and the resin, in the state of a very* thin film, was kept twelve hours at a temperature not exceeding 180° FAHR. Previous to analysis the heat was raised for one hour to 212° FAHR. The resin was very brittle, in thin fragments, was of a pale brown colour, and preserved the characteristic odour.

7.995 grs. gave $\bar{C} = 18.55$, and $\bar{H} = 4.785$ grs.

3. A third portion being evaporated at a gentle heat was fused for two hours at 212° FAHR.

7.62 grs. gave $\bar{C} = 17.64$, and $\bar{H} = 4.633$ grs.

4. The resin of a fourth portion, after long exposure to a gentle heat, was fused for a few minutes at 250° FAHR.

7.69 grs. gave $\bar{C} = 18.05$, and $\bar{H} = 4.61$ grs.

* A grain of the resin being spread over at least a square inch of surface.

5. A fifth portion after long heating at 212° , owing to the drying of the water-bath, was allowed to remain for some time at a higher temperature. Its colour was in some degree darker.

7.36 grs. gave $\ddot{C} = 17.67$, and $\dot{H} = 4.50$ grs.

These results give per cent. respectively,

1. At 212° for a short time.	2. 12 hours at 180° and 1 hour at 212° .	3. 2 hours at 212° .	4. Fused at 250° .	5. Half an hour at $250^{\circ} \pm$.
Carbon 63.21	64.15	64.01	64.90	66.38
Hydrogen 6.66	6.66	6.75	6.66	6.79
Oxygen 30.13	29.19	29.24	28.44	26.83
100	100	100	100	100

From the mode in which these several specimens of resin were prepared, it is obvious that Nos. 2 and 3 represent most nearly the normal state of the resin. In No. 1 so much of the volatile matter remained as to prevent the resin from entirely concreting; while in 4 and 5 the heat had been raised, or prolonged, so as to cause partial decomposition. The formula $C_{40} H_{25} O_{14}$ gives

		Per cent.
40 Carbon	= 3057.480	64.15
25 Hydrogen	= 311.99	6.52
14 Oxygen	= 1400.000	29.33
	4769.47	100

which agrees very closely with the results of the second and third analyses, while those of the first and fourth analyses oscillate on either side of the calculated numbers. We seem to be justified therefore in adopting this formula for the constitution of the resin of opoponax, as it exists in the natural gum resin of commerce.

In reference to the analyses 4 and 5 above given, I would draw attention to a fact which may hereafter prove of considerable consequence when we come to consider the rational constitution of the resins. It will be observed that, by an increase of temperature, sufficient to produce partial decomposition, the carbon increases, while the per centage of oxygen decreases almost in equal proportion, that of the hydrogen remaining nearly constant. This was the case also as above shown with the resin of retin-asphalt, and approximately also with that of ammoniac, and we shall have occasion to make the same remark in regard to several other resins to be treated of in the following sections. I may mention, especially that of assafetida, with the analysis of which I propose to conclude the present part of these researches.

The nature of this action of an elevated temperature is shown more clearly by

comparing the *atomic* constitution of the resin before and after being heated. Thus the fifth analysis of the resin of opoponax gives

Carbon	66.38	4	atoms.
Hydrogen	6.79	25.09	atoms.
Oxygen	26.83	12.4	atoms.
		100	

by which we see that the oxygen diminishes much more rapidly than the hydrogen; that water or a carbo-hydrogen are not alone given off, but along with these, if evolved at all, there is evolved another substance also of more complicated constitution.

XVI. *Resin of Assafoetida.*

I. The assafoetida of the shops loses little in bulk when digested in cold alcohol of 0.83, but it gives a pale-yellow solution, from which, by evaporation, a resin of the same colour is obtained. This resin has the characteristic odour of the gum resin, and the property which the natural product also possesses of becoming purple when exposed to the sun's rays. Laid as a thin coating upon paper, the pure resin is much more sensible to the sun's rays than the resin of guaiacum, and affords a much more beautiful colour. It is readily and completely soluble in cold alcohol and ether. Like many other resins it must be heated for a length of time before it becomes hard and brittle, and reaches its normal state. By this prolonged heating it acquires a darker and brownish colour, and is easily decomposed if the temperature be raised much above 212° FAHR. As the temperature rises, the resin froths up very much for some time, giving off a strong garlic odour; it then flows quietly till the heat is again increased. When completely burned, the resin employed in the following analyses left 0.18 per cent. of brown ash.

1. A small portion of the solution was evaporated and heated in the state of a thin film for forty-eight hours to 180° FAHR., and afterwards for six hours to 212° FAHR. The resin was brittle.

5.79 grs. gave $\bar{C}$ = 14.52, and $\bar{H}$ = 3.93 grs.

2. A second portion was evaporated and digested for many hours at 212° FAHR.

8.19 grs. gave $\bar{C}$ = 20.66, and $\bar{H}$ = 5.55 grs.

3. Of the same, a portion heated twelve hours longer, and from that cause a little darker in colour,

6.02 grs. gave $\bar{C}$ = 15.32, and $\bar{H}$ = 4.14 grs.

4. Of the same mass, a portion was heated very gently in a platinum capsule over a lamp, and kept in a state of fusion for an hour. The heat was not sufficient to drive off any visible fumes, but the odour of the resin became much weaker. In this state

6.56 grs gave $\bar{C}$ = 16.82, and $\bar{H}$ = 4.475 grs.

These results, allowing 0.2 per cent. for foreign matter, are equal to

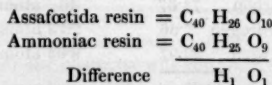
Heated 48 hours at 180 and 6 hours at 212° FAHR.	Heated long at 212° FAHR.	Heated 12 hours longer at 212° FAHR.	Heated over the lamp 1 hour at 220°
Carbon 69.49	69.90	70.51	71.05
Hydrogen 7.56	7.55	7.65	7.59
Oxygen 22.95	22.55	21.84	21.36
100	100	100	100

The formula $C_{40}H_{26}O_{10}$, gives

40 Carbon	= 3057.48	Per cent.
26 Hydrogen	= 324.47	69.75
10 Oxygen	= 1000.00	7.44
		22.81
	4381.95	
		100

These numbers agree very closely with the result of the second analysis, and do not deviate much from the numbers deduced from the first and third analyses. For other reasons, besides this accordance, I am inclined to consider the portion employed in the second analysis as approaching nearest to the normal state of the resin, and have, therefore, no reason at present to doubt that the formula $C_{40}H_{26}O_{10}$, represents very nearly the true constitution of the resin as it exists in the crude assafoetida of commerce.

II. If we compare with each other this formula and that deduced for the resin of ammoniac, from the analyses above given, we observe that they differ only in the presence, in assafoetida resin, of the elements of one atom of water more than are contained in the ammoniac resin. Thus



On this coincidence I believe little reliance is to be placed, inasmuch as in neither resin is the number of atoms of hydrogen to be considered as *certain*; it nevertheless suggests the inquiry—can any number of these resins be hydrates of a common radical, or does water as such enter into their constitution? In so far as the direct application of heat is concerned, we have already seen*, in the case of opoponax and ammoniac resins, that when the temperature is increased so as to cause incipient decomposition, the elements are not given off in such proportion as to form water only. Water may be one of the products of the decomposition by heat, but if it existed as such in the resin, why should other products be always evolved along with it?

By comparing the relative atomic proportions of the elements as obtained in the four analyses of assafoetida resin above detailed, we shall be satisfied that though the

* See pp. 351 and 353.

resins appear to be so related, yet that of assafoetida is not be considered as a hydrate of the resin of ammoniac. Thus the

	Carbon.	Hydrogen.	Oxygen.
First analysis gave	40 atoms.	26.7 atoms.	10.18 atoms.
Second	40 atoms.	26.4 atoms.	9.96 atoms.
Third	40 atoms.	26.6 atoms.	9.55 atoms.
Fourth	40 atoms.	26.2 atoms.	9.3 atoms.

Now, allowing a similar error in the hydrogen in the four analyses, we see that the hydrogen and oxygen by no means diminish in the ratio in which they enter into the constitution of water. Taking No. 2 as the normal state of the resin, we find that in No. 4 the loss of hydrogen was 0.2 of an atom, while that of oxygen was 0.66, or three times as much as was necessary to form water with the hydrogen. In the volatile substance which escapes during the heating, therefore, the oxygen is to the hydrogen in atoms as 3:1, while in the resin itself they are nearly as 2:5. We have seen that in ammoniac and opoponax resins, the volatile matter given off in heating to incipient decomposition, also contains more oxygen in proportion to the hydrogen than exists in the resin itself.

III. As the resin, when heated gently over the lamp, and kept for a length of time in fusion, approached in composition to a formula containing nine of oxygen (see fourth analysis above), I heated a second quantity very gently under the same circumstances, and kept it in fusion for six hours; there was no frothing; the resin nearly lost its smell, and became slightly darker in colour. It was more brittle, and the fragments showed still less tendency to cohere than before.

6.42 grs. (6.407 grs. pure resin) gave $\bar{C} = 16.535$, and $\bar{H} = 4.425$ grs., or per cent.,

Carbon	71.37	40 atoms.
Hydrogen	7.66	26.3 atoms.
Oxygen	20.97	9.05 atoms.

100

This result is in exact accordance with those of the other analyses, and with the remarks already made in regard to the comparative rapidity with which the oxygen diminishes. For while the analysis of the resin in its normal state (No. 2) gave

Carbon.	Hydrogen.	Oxygen.
40 atoms.	26.4 atoms.	9.96 atoms,
40 atoms.	26.3 atoms.	9.05 atoms.

so that by prolonged fusion at a temperature of about 250° , till it nearly loses its smell, the resin $C_{40}H_{26}O_{10}$ changes into $C_{40}H_{26}O_9$. The changed resin is still easily and completely soluble in cold alcohol of 0.84.

IV. We have seen that the alcoholic extract of the labdanum of commerce may be represented by $C_{40}H_{33}O_8$, and that by boiling in water a resin $C_{40}H_{33}O_7$ * is obtained;

* See under labdanum resin, p. 345.

this is precisely analogous to the change effected as above, by heating the resin of assafœtida. With the view of ascertaining how far mere boiling in water would produce this change upon assafœtida, I digested a portion of the crude resin of commerce in alcohol, poured the filtered alcoholic solution into a large quantity of boiling water, and boiled the mixture for an hour. Along with the alcohol a volatile oil escaped into the atmosphere, which diffused a powerful odour through the room, and which as it came forth from the mouth of the flask affected the eyes, like the fresh juice of the onion. After this prolonged boiling the smell nearly disappeared, and on cooling the solution, the greater part of the resin subsided slowly in the form of a yellow powder, the supernatant liquid remaining turbid for many days. The yellow powder dissolved readily, largely, and without residue, in cold alcohol. Evaporated and heated to 212° FAHR. for eight hours in a thin film, it gave a resin which at first was rapidly coloured by exposure to the light, and by the prolonged heating acquired a decidedly reddish brown colour.

6.5 grs. (6.487 grs. pure resin) gave $\bar{C} = 16.76$, and $\bar{H} = 4.485$, or per cent.,

Carbon	71.43
Hydrogen	7.68
Oxygen	20.89

100

This result agrees almost exactly with that yielded by the resin after long heating over the lamp, and like it agrees with the formula $C_{40} H_{26} O_9$.

I refrain at present from discussing the question which suggests itself—whether we ought to consider the resin thus boiled and heated, or as it is obtained directly from the natural product by means of alcohol, to be in its normal state; or whether the presence of a quantity, perhaps variable, of a volatile oil be the only source of the different formulæ deduced from the analyses of the resin in its two states? This and other questions of a similar character will find their true solution as our investigation proceeds, and our knowledge of the constitution, mutual relations, and transformations of the resins becomes more extended.

The solution of the crude resin of assafœtida in alcohol gives a bulky, white, curdy precipitate, with an alcoholic solution of acetate of lead. I have analysed this salt, but the result is such as, with other similar results, to indicate the necessity of an extended inquiry into the constitution of the salts of this and the other resins. This inquiry I propose to enter upon on a future occasion.

Note.—The odour of this resin suggests the possibility of its containing sulphur as a constituent. Boiling nitric acid dissolves the resin completely, with evolution of red fumes, but the solution diluted with water and filtered, gave no trace of a precipitate with chloride of barium. It was burned also by projecting it in small fragments into a flask containing a fused mixture of chlorate of potash and common salt. The mixed salts were afterwards dissolved, but no milkiness was occasioned by chloride of barium.



General Remarks.

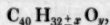
At the close of the former Part (III.) of these researches, I stated that a slight change in the general formulæ we had seen reason to adopt, as representations of the constitution of the resins, would be rendered necessary by certain analyses which I had already made, but which were not in a state for publication. Some of these analyses are contained in the present paper, and I shall here shortly advert to the modifications they suggest.

I. As a general expression for all the resins of which the composition was then known, I proposed the irrational formula $C_{40} H_{32-x} O_y$, in which x varied from 0 to 12, and y from 1 to 12. No resins were then known which had been shown with any degree of certainty to contain more than thirty-two of hydrogen to forty of carbon.

II. Observing also that those resins in which the hydrogen was less than twenty-four atoms possessed physical and chemical properties analogous to each other, yet remarkably distinct from those exhibited by the resins in which the hydrogen approached to thirty-two atoms, I was induced to subdivide the resins into two sections, represented respectively by

$C_{40} H_{32-x} O_y$, of which colophony is to be regarded as the type; and
 $C_{40} H_{24-x} O_y$, of which gamboge and dragon's blood are members.

III. In the present paper, however, are introduced three resins, those of scammony ($C_{40} H_{33} O_{20}$), jalap ($C_{40} H_{34} O_{18}$) and labdanum ($C_{40} H_{33} O_7$), in which the hydrogen exceeds thirty-two atoms. To include these, therefore, our first *sectional* formula must be modified by the insertion of the plus (+) after 32, giving it the form



in which state it includes the three resins above-mentioned, in which the hydrogen is present in greater quantity.

It may, perhaps, become a question hereafter whether these resins ought not to be placed in a separate section, represented by $C_{40} H_{32+x} O_y$, since their properties, and especially their action upon the system, is so very different from that of any of the resins of the pine tribes, of which colophony is the type. This point, however, will become more clear after the other resins usually classed by systematic writers along with those of scammony and jalap have been examined and analysed.

In connexion with this alteration in our formula deduced from the analyses above given, I ought to advert to two formulæ for the *crystallized resin of elemi*, lately published by Professors HESS of Petersburg and H. ROSE of Berlin*. The former chemist assigns to this resin the formula $C_{40} H_{33} O$, and the latter $C_{40} H_{34} O$, differing only in regard to the presence or absence of one atom of hydrogen. Whichever of these formulæ be adopted, the change above introduced into our general expression

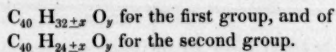
* See POGGENDORFF's Annalen, vol. xxxiii. p. 51; vol. xlii. p. 322; vol. xlvii. p. 61; vol. xlix. p. 219.

would be rendered necessary had we not been previously led to it by the resins, of which the analysis is given in the present paper.

I have frequently had occasion in the course of this investigation to advert to the difficulty I have experienced in deciding which of two numbers to adopt as representing the equivalents of hydrogen in a given resin, and to state how very little reliance I could myself place on the exactitude of the numbers I was induced to prefer as the most probable. There are, apart from errors of manipulation, difficulties in the way of these analyses, arising from the presence of volatile matter in some of the resins, and from the ease with which others are decomposed, which make me willing to distrust my own formulæ to the extent of one atom of hydrogen at least in each. I am not surprised, therefore, at the different results obtained by the distinguished chemists above-named in regard to the crystallized elemi resin, nor do I consider that the error, on whichever it may rest, is to be attributed to any want of dexterity in either of these excellent manipulators, but rather to the nature of the resin itself, and to the manner or length of time during which it has been previously heated.

IV. The analyses contained in the present paper exhibit the necessity also of a similar change in our second sectional formula, $C_{40} H_{24-x} O_y$. The resins of ammoniac and opoponax contain twenty-five, that of assafoetida twenty-six, and that of retin-asphalt twenty-seven atoms of hydrogen, while the latter alone approaches in any of its properties to the resins of the colophony type. Without inquiring closely, therefore, where the limits of the two groups are to be placed, I propose at present to insert the sign plus in this formula also, with the view of including in it the resins above-named, leaving to a future opportunity the discussion of the precise place in our groups or sub-groups which any particular resin ought to occupy.

Our general expressions, therefore, now assume the form of



To these irrational expressions I would not be understood as annexing any *permanent* value. They are intended merely to symbolize the present state of our knowledge on this subject. New researches will necessarily introduce modifications, and make us acquainted at length with expressions much more general, and assuming perhaps a different form.

V. In reference to the points of theory, with a view to the determination of which the present inquiry was undertaken, as stated at the commencement of this series of papers, we are already prepared I think to infer, that the resins are not all derivable from one common radical. Whether we are to consider the members of each of our great groups as compounds of a common radical, or the members of those sub-groups only, in which the atoms of hydrogen are constant while those of the oxygen vary, —whether the radical they contain be a binary compound of carbon and hydrogen, or ternary, and contain oxygen; whether the resins in general be simply oxides of such

radicals, or hydrates containing the elements of water in a state of direct combination; or whether they be not rather formed by the union of two or more compound oxides; these are questions the greater number of which we are as yet far from being prepared to discuss with any chance of arriving at the truth. I waive, therefore, the consideration of all these points for the present, in the hope that light will spontaneously break in upon many of them, when in a succeeding part of this research I shall study the relations of the resins to the most important chemical reagents.

One important point may be considered as nearly established by the analyses already made, namely, that the constant C_{40} is *characteristic* of the irrational formulæ for this group of natural productions; and it is interesting to find that in exhibiting such a characteristic, it bears a striking resemblance to other groups, not very distantly allied to it, either in the physical properties they possess, or the natural sources from which they are obtained. I refer especially to the fixed and volatile oils, in many of the known formulæ for which a similar constant C_x is to be traced, and in which the number represented by x may be considered as characteristic of a more or less extensive natural group. I shall have an opportunity of illustrating this observation in a future paper.

Durham, March 13, 1840.

XIX. *On the Constitution of the Resins. Part V.* By JAMES F. W. JOHNSTON, Esq.,
M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham.

Received June 4,—Read June 18, 1840.

XVII. *Resin of Sagapenum.*

THE gum resin of sagapenum has an odour very much resembling that of assafoetida, but less powerful. Like the latter gum resin, it also gives, when treated with alcohol, a pale yellow solution, while the greater portion of the mass remains undissolved. The white matter which is left behind after exhaustion with alcohol, is soluble in water, giving a milky solution.

The alcoholic solution, when evaporated, gives a pale-yellow resin, having a strong garlic odour, melting readily, and becoming fluid at 212° FAHR.

A portion of the resin prepared by evaporating the alcoholic solution at 212° , was treated for two hours with repeated portions of boiling water. The water came off colourless, but had a powerful odour of the resin, and a slightly bitter taste, leaving in the mouth an after-taste of onions. After drying it for a length of time at 212° , the resin was again dissolved in alcohol, filtered and evaporated in a thin film. It was then heated at 150° FAHR. for sixty hours, at which temperature it was still semifluid.

Burned in the air it left 0.22 per cent. of ash.

A. 8.585 grs. (8.566 grs. of pure resin) gave $\bar{C} = 21.170$, and $\bar{H} = 6.558$ grs.

B. Further fused at 212° FAHR. for several hours, the colour became deeper yellow than before. When cold it was brittle but soft, and the particles readily cohered. In this state

10.11 grs. (10.088 grs. pure resin) gave $\bar{C} = 25.84$, and $\bar{H} = 7.835$ grs.

These results give per cent.

	A.	B.	$C_{40} H_{29} O_9$ gives
Carbon	70.05	70.83	70.78
Hydrogen	8.51	8.63	8.38
Oxygen	21.44	20.54	20.84
	100	100	100

We may, therefore, consider the resin of sagapenum thus extracted, to be represented by $C_{40} H_{29} O_9$.

MDCCCXL.

3 A

XVIII. *Resin of Galbanum.*

The galbanum resin of commerce dissolves only in small quantity in alcohol, leaving a large insoluble residue, which is principally composed of gum. Evaporated at 212° FAHR., the yellow alcoholic solution gives a beautiful brownish-yellow transparent resin, fusing readily at that temperature, and emitting the peculiar fetid odour of this class of resins. Treated with boiling water, it imparted no colour to it.

1. After washing with boiling water, and subsequently heating for several days at 150° FAHR., it left when burned in the air 0.3 per cent. of white ash. Burned with oxide of copper,

A. 7.01 grs. (6.988 grs. pure resin) gave $\bar{C}$ = 18.69 grs., and $\bar{H}$ = 5.21 grs.

B. After further heating, 8.08 grs. (8.055 pure resin) gave $\bar{C}$ = 21.64, and $\bar{H}$ = 6.22 grs.

C. And 8.005 grs. (7.98 pure resin) gave $\bar{C}$ = 21.4, and $\bar{H}$ = 6.15 grs., or per cent.,

	A.	B.	C.
Carbon	73.99	74.33	74.15
Hydrogen	8.29	8.58	8.56
Oxygen	17.82	17.09	17.29
	100	100	100

The formula $C_{40} H_{28} O_7$, gives

		Per cent.
40 Carbon	= 3057.480	74.45
28 Hydrogen	= 349.426	8.50
7 Oxygen	= 700.000	17.15
	4106.906	100

2. The close approximation between the theoretical and experimental per centage of hydrogen (in B and C) rendering this formula a little suspicious, I evaporated a second small quantity of the alcoholic solution of this resin, washed it with boiling water, and heated it long in a thin film at 200° FAHR. Of this, on analysis,

A. 6.486 grs. (6.467 grs. pure resin) gave $\bar{C}$ = 17.13 grs., and $\bar{H}$ = 4.892 grs.

B. 7.533 grs. (7.51 grs. pure resin) gave $\bar{C}$ = 20.17, and $\bar{H}$ = 5.72 grs., or per cent.,

	A.	B.
Carbon	73.27	74.26
Hydrogen	8.40	8.46
Oxygen	18.33	17.28
	100	100

In the first of these analyses there is, from some cause, a considerable deficiency of carbon, but the quantity of water, in regard to the accurate determination of which great pains were taken, being in both analyses less than is required by the formula

$C_{40} H_{28} O_7$, I think it more safe to represent the resin of galbanum by the formula $C_{40} H_{27} O_7^*$.

$$C_{40} H_{27} O_7 \text{ gives } \begin{cases} \text{Carbon} & 74.67 \\ \text{Hydrogen} & 8.23 \\ \text{Oxygen} & 17.00 \end{cases}$$

100

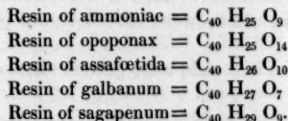
The carbon by calculation is a third per cent. more than was found by experiment. But this is the direction in which errors of experiment in organic analyses are generally found, and a slight deficiency in the carbon may be expected in the case of substances which so readily fuse and give off volatile matter as this and many other of the resins. In pumping out the hygrometric moisture, some volatile vapour may also be exhausted.

3. When heated over the lamp in a platinum capsule to a temperature of about 300° Fahr. , the resin above analysed gave off white fumes, and after two hours had lost nearly 10 per cent. of its weight, having become of a beautiful brownish-red colour. It still softened at 212° Fahr. , and retained a little of its original odour. In this state 7.11 grs. = 7.086 pure resin, gave $\bar{C} = 19.02$, and $\bar{H} = 5.18$, or per cent.,

Carbon	74.22	40	atoms.
Hydrogen	8.12	26.7	atoms.
Oxygen	17.66	7.27	atoms.
100			

In this result we see an apparent approximation to the formula $C_{40} H_{26} O_7$, the hydrogen decreasing, while the oxygen appears to increase.

In the former of this series of papers (Part IV.), I gave the analysis of the resins of ammoniac, opoponax, and assafoetida, which together with those of sagapenum and galbanum, constitute the group of foetid resins of some chemists†. The odour of the last four of these resins is very similar, though that of assafoetida is the most powerful and disagreeable. We might anticipate, therefore, some resemblance in constitution among these resins, since they exhibit in common this very striking property. In the *irrational* formulæ above obtained, however, we do not recognize any close resemblance, either in the proportions of hydrogen or of oxygen which they contain. Thus the



* See under elemi resin B.

† Thomson's Organic Chemistry (1838), p. 567.

Still it appears to me exceedingly probable, that in the *rational* formulæ for this and similar groups of resins exhibiting striking sensible properties, common to all, we may hereafter find that connexion in constitution which the *irrational* formulæ do not exhibit, and the absence of such connexion is not without its weight in favour of the opinion, that the resins in general are not mere oxides of a carbo-hydrogen radical, but are in many cases at least made up of two or more compound radicals. Into the consideration or development of this view, I do not propose to enter, until, in the sequel of the present and in some subsequent papers, I shall have brought forward facts and analytical results by which it may be better sustained.

XIX. *Euphorbium Resin.*

This resin occurs in commerce in the form of tears, generally enveloping small twigs or thorns of the shrub from which it had exuded. It is largely mixed with seeds and spines, and sometimes with at least three-fourths of its weight of clay and other earthy matters. It is of a pale-yellow colour, and is distinguished by its peculiarly hot and acrid taste, and its stimulating action on the organs of smell and even externally upon the skin.

When digested in cold alcohol (0·8) a pale-yellow solution is obtained, which by evaporation gives a yellow resin. After being treated with cold alcohol as long as anything is taken up, a large insoluble residue remains. Boiled in alcohol, this residue yields a solution, from which, on cooling, a white resinous substance is deposited in a crystalline form. This sparingly soluble resin has been examined and analysed by Rose. To the results of these analyses I shall presently have occasion to advert.

I. *Resin A. of Euphorbium (readily soluble in cold alcohol).*

1. When the native tears of euphorbium are digested in cold alcohol, a pale-yellow solution is obtained, and from this by evaporation, a brownish-yellow resin, readily fusing at 212° . If this resin be treated with boiling water, the first portion of the liquid employed acquires a pale-yellow tinge, and a small quantity of oil is removed. By subsequent washing nothing further appears to be taken up by the water. Separated from the water, the resin is pale-yellow and opaque, like common Burgundy pitch, and requires long drying at 212° in a thin film to render it perfectly dry and transparent. It is now less fusible, though it still becomes semifluid at 212° , and when cold is brittle, in mass of a brownish red colour, and in fragments exceedingly electric.

In this state, when burned in the air, 5·605 grs. left 0·075, or 1·34 per cent. of ash; and with oxide of copper,

A. 9·1 grs. (8·978 grs. pure resin) gave $\bar{C} = 24\cdot39$, and $\bar{H} = 7\cdot91$ grs.

B. 7·19 grs. (7·094 grs. pure resin) gave $\bar{C} = 19\cdot29$, and $\bar{H} = 6\cdot3$ grs.

These are equivalent to

	A.	B.	$C_{40}H_{31}O_6$ gives
Carbon	75.12	75.21	75.59
Hydrogen	9.79	9.87	9.56
Oxygen	15.09	14.92	14.85
	100	100	100

2. The same portion of crude euphorbium being treated with a second quantity of cold alcohol, gave a solution from which the resin was obtained as above described, washed with water and dried at 212° FAHR. When burned in the air it left 1 per cent. of ash.

A. 7.71 grs. (7.61 grs. pure resin) gave $\bar{C} = 21.0$, and $\bar{H} = 7.03$ grs.

B. 8.19 grs. (8.075 grs. pure resin) gave $\bar{C} = 22.28$, and $\bar{H} = 7.38$ grs.; or per cent.,

	A.	B.	
Carbon	76.29	76.30	40 atoms.
Hydrogen	10.26	10.15	32.6 atoms.
Oxygen	13.45	13.55	5.43 atoms.
	100	100	

The difference between the results obtained from this and from the former portion, may be ascribed either to a difference in the mode of heating the two portions, the latter after drying at 212° FAHR. having been further fused at a slightly elevated temperature, when bubbles of volatile matter began to show themselves; or to an admixture of the less soluble resin (B.) contained in the euphorbium of commerce, which according to the analysis of ROSE, contains more hydrogen and less oxygen than are present in the more soluble resin (A.). At all events the fractional atom of oxygen exhibited by the results of these second analyses, shows that the portion analysed is not to be considered as a pure resin.

3. To determine this point the crude resin was treated with a third portion of cold alcohol, and the solution, which was much paler in colour and less concentrated than either of the former, was submitted to evaporation. As the alcohol was drawn off, the solution became milky, and gradually deposited a portion of a white powder, which was the second resin of euphorbium. This resin, therefore, is soluble to some extent in cold alcohol, and is consequently capable of being taken up along with the more soluble resin, and in greater quantity, of course, by the second than by the first portion of alcohol with which the tears may be treated.

The remainder of the second portion which had been analysed, when treated with a small quantity of alcohol, readily dissolved, with the exception of a slight residue, which resembled the powder of the second resin. It is not unlikely, therefore, that even the resin employed in the first series of analyses might contain a little of resin B, by which the carbon and hydrogen would be slightly increased. The formula $C_{40}H_{31}O_6$ deduced from them, though agreeing very closely with the experimental

results, must still be considered as open to suspicion, and be regarded only in the light of an approximation. The same remark applies also to the resin A. of elemi, though to a less extent, since the resin B. of elemi is less soluble than resin B. of euphorbium.

II. Resin B. of Euphorbium.

This resin has also been analysed by ROSE, who obtained

Carbon	81.47	81.70	40 atoms.
Hydrogen	11.33	11.36	34.6 atoms.
Oxygen	7.20	6.94	2.5 atoms*.
	100	100	

Rose thinks it probable that the resin he analysed was not quite pure, which is rendered very probable by his results not agreeing with any formula of which C_{40} is a member. I have not hitherto obtained it in sufficient quantity to enable me to repeat his analysis; when I shall hereafter describe the results of experiments on the relation of the resin A. to certain powerful reagents, I hope to have an opportunity of again adverting to the constitution of resin B. of euphorbium.

This resin is considered by ROSE to be probably isomeric with the resin B. of elemi, but the difference in their physical characters and solubility, supposing no reliance to be placed on the analyses, appear sufficient to render that opinion very doubtful.

XX. Elemi Resin.

The elemi resin of commerce, like that of euphorbium, consists of two resins, one readily soluble in cold alcohol, the other dissolving, to any extent, only in boiling alcohol, and falling again in great measure as the liquid cools. The soluble resin has the ordinary resinous aspect, is transparent, brittle, brownish yellow, and forms salts with the bases; the sparingly soluble resin falls in colourless crystals, which melt at $300^{\circ} + \text{FAHR.}$ into a colourless fluid, becoming when cold a nearly colourless brittle mass with a resinous fracture, the solution of which does not precipitate bases.

The crystallized resin has been analysed by ROSE, HESSE, and MARCHAND, and its composition determined with considerable accuracy, and I have thought it necessary to submit it to a further examination, chiefly for the purpose of comparing my results with those obtained by these distinguished chemists.

I. Resin A. of Elemi (readily soluble in cold Alcohol).

Reduced to powder and digested with cold alcohol, the crude elemi resin gives a yellow solution, which by evaporation yields a yellow resin. When nearly free from alcohol this resin emits a strong odour of oil of lemons. Treated with boiling

* ROGGENDORFF'S Annalen, xxxiii. p. 53.

water it loses its transparency and becomes white and opaque, but imparts no colouring matter to the water. Thus prepared and long dried at 212° FAHR., it left when burned in the air 0.10 per cent. of ash.

A. 8.31 grs. (8.302 grs. pure resin) gave $\bar{C} = 23.7$, and $\bar{H} = 7.9$ grs.

B. 8.04 grs. (8.032 grs. pure resin) gave $\bar{C} = 22.71$, and $\bar{H} = 7.45$ grs.

C. 7.465 grs. (7.458 grs. pure resin) gave $\bar{C} = 21.26$, and $\bar{H} = 6.998$ grs.

	A.	B.	C.	$C_{46}H_{32}O_2$ gives
Carbon	78.93	78.15	78.82	79.275
Hydrogen	10.57	10.30	10.43	10.355
Oxygen	10.50	11.55	10.75	10.370
	100	100	100	100

II. Resin B. of Elemi (*very sparingly soluble in cold, more largely in boiling Alcohol, out of which it crystallizes on cooling*).

This resin remains in the form of a white powder when the natural elemi resin is exhausted with cold alcohol, as long as a coloured solution is obtained. This white powder dissolves in boiling alcohol, and yields the pure resin in the state of minute white crystals as the solution cools. The constitution of this resin appears to be pretty well established, having been analysed by HESSE, ROSE, and MARCHAND, with results which are very closely accordant.

The specimen I analysed, after drying between folds of bibulous paper, had been long heated at 200° FAHR., and was then in the state of a white powder.

A. 6.893 grs. gave $\bar{C} = 21.265$ grs., and $\bar{H} = 7.395$ grs.

B. 6.76 grs. gave $\bar{C} = 20.78$ grs., and $\bar{H} = 7.2$ grs.

These results compared with those of the other experimenters, give per cent.

	HESSE.		ROSE.		MARCHAND.		JOHNSTON.	
Carbon	85.36	85.06	85.11	85.61	85.54	85.59	85.30	85.00
Hydrogen	11.51	11.54	11.79	11.83	11.61	11.59	11.92	11.83
Oxygen	3.13	3.40	3.10	2.56	2.85	2.82	2.88	3.17
	100	100	100	100	100	100	100	100

The only difference of any consequence among these analyses is in the amount of hydrogen. I have given only two of the results published by each of the above chemists, but in three others published by ROSE, the hydrogen amounted to 11.85, 11.89, 11.98 respectively. Finding the quantity of hydrogen deduced from my first analysis to be so high, I used greater precautions in pumping out the hygrometric moisture in the second, but without bringing it much nearer the results of HESSE or MARCHAND. Still the formula adopted by HESSE is that which must be adopted as the most probable, if any allowance is to be made in the analyses of MARCHAND, ROSE, and my-

self for an error of hydrogen in excess. Thus

HERSEY'S formula $C_{40}H_{33}O_1$ gives	while $C_{40}H_{34}O_1$ gives
Carbon 85.66	85.36
Hydrogen 11.53	11.85
Oxygen 2.81	2.79
100	100

The quantity of hydrogen, 11.85, in the second column is greater than the minimum of water either in ROSE'S analyses or mine, and therefore according to the principle adopted in deducing all the formulæ exhibited in the present series of papers, $C_{40}H_{33}O_1$ is that which these analyses indicate as the most probable. It is chiefly, I believe, to the hygrometric state of the oxide of copper, that analyses performed according to the *method of LIEBIG* and with equal care, differ slightly in the amount of hydrogen. If the oxide be newly prepared by calcining the nitrate, and be therefore in a minute state of division, it appears almost impossible, as a *general result*, to free it so completely from moisture that the hydrogen shall not be 0.2 to 0.3 per cent. in excess, while the same experimenter will come within 0.1 or 0.15 per cent. by the use of oxide of copper, which has been frequently heated to redness, and after having been used for analysis, has been repeatedly re-oxidized by heating in a current of air.

XXI. Resin of *Bdellium*.

The resin of bdellium occurs in commerce, in translucent yellow rounded masses, often of considerable size. The masses vary in tint, as is the case with many other resins, some of them being of a brown colour, more or less dark.

A single yellow mass, about half an inch in diameter, was reduced to powder and digested in cold alcohol. A pale yellow solution was obtained, from which, by evaporation in a thin film, a yellow resin was obtained. It was treated with successive portions of boiling distilled water, of which only the first portion acquired a slightly yellow tinge. By this treatment it scarcely lost its transparency, differing in this respect very much from the soluble resins of euphorbium and elemi above-described. The resin was then dried for forty-eight hours at 180° FAHR. in the state of a thin film. It now formed a beautiful transparent yellow resin, softening readily at 212° , and at that temperature emitting a slightly fragrant resinous odour. Burned in the air it left 0.17 per cent of ash.

A. 7.29 grs. (7.277 grs. pure resin) gave $\ddot{C} = 20.15$, and $\dot{H} = 6.54$ grs.

B. 7.185 grs. (7.172 grs. pure resin) gave $\ddot{C} = 19.77$.

C. Another lump was treated in a similar manner, and the resin similarly dried. Of this

7.687 grs. (7.673 grs. pure resin) gave $\ddot{C} = 21.13$, and $\dot{H} = 6.97$ grs.

D. Of the alcoholic solution of the resin from the same lump, another portion was

evaporated separately and much longer heated, when 6.44 grs. (6.429 grs. pure resin) gave $\bar{C} = 17.97$, and $\bar{H} = 5.715$ grs.

These results give per cent.,

	A.	B.	C.	D.
Carbon	76.57	76.22	76.15	77.29
Hydrogen	9.98		10.09	9.87
Oxygen	13.45		13.76	12.84
	100		100	100

The result of analysis D. agrees very closely with the formula $C_{40}H_{31}O_5$, which gives

		Per cent.
40 Carbon	= 3057.480	77.51
31 Hydrogen	= 386.867	9.81
5 Oxygen	= 500.000	12.68
	3944.347	100

I consider the portion last analysed (D.) to have been most nearly in the normal state, and the result obtained to be the more trustworthy, from the near approximation to the calculated numbers above given. It would appear, therefore, that the different lumps of the natural resin of bdellium, as it is met with in commerce, contain the same resinous substance, and that after extraction by alcohol and repeated washing with boiling water, this resin requires prolonged heating at a temperature of 200° FAHR. in the state of a thin film, to free it from water and other volatile matters, and bring it to its normal state.

The formula $C_{40}H_{31}O_5$ is that assigned in the third part of these researches* to the resin A. of sandarach, which differs from that of bdellium, however, in being a sparingly soluble resin. Whether these resins be really isomeric, or whether they differ by an atom of hydrogen more or less, will be investigated in a future paper.

The insoluble matter which remains after the natural resin of bdellium is exhausted with cold alcohol, consists only of gum, and is taken up by boiling water.

XXII. Resin of Benzoin.

The resin of benzoin is one to which considerable interest attaches from its connexion with benzoic acid, and the numerous series of remarkable compounds, to the knowledge of which the study of that acid has led. I commenced the study of it, therefore, with the hope, not merely of elucidating its relation to the other resins, but also of throwing some light upon that which it bears, or may be expected to bear, to the acid so readily obtained from it. In the latter expectation, however, I have for the present been in some measure disappointed, in so far at least as I have failed to obtain a formula for this resin, by which its rational connexion with the radical benzyloyle, and its derivatives, can be, if not satisfactorily comprehended, at least numeri-

* Philosophical Transactions, 1839, p. 294.

cally stated. The investigation of this resin indeed has presented many difficulties, chiefly, as it appears to me, from the ease with which it undergoes a partial decomposition even at very moderate temperatures. I have made numerous analyses of it, in various states, with the view, if possible, of establishing a formula for it in the normal state, and, amid the many changes it undergoes, of arriving at a process by which it may always be obtained of uniform composition. How far this end has been attained the following experiments will show.

The resin of benzoin, as it occurs in commerce, consists of brown opake brittle masses, containing here and there small pieces of a yellowish white colour and semi-transparent. These latter portions melt at about 200° FAHR. into a transparent nearly colourless resin, which on cooling becomes brittle. At a higher temperature it gives off water and benzoic acid, and becomes brown.

1. Of this pure white variety a portion was dissolved in alcohol, evaporated and heated in a thin film at 212° FAHR. till it ceased *sensibly* to evolve benzoic acid. During this heating it gradually assumed a brownish tinge. In this state, when burned in the air, it left 0.29 per cent. of ash.

7.64 grs. (7.618 grs. pure resin) gave $\bar{C}$ = 19.60, and $\bar{H}$ = 6.84 grs.

2. The colourless resin in its natural state, without being dissolved, was kept for twenty hours in a semifused state at 200° FAHR. It left, when burned in the air, 0.24 per cent. of ash, and

9.87 grs. (9.847 grs. pure resin) gave $\bar{C}$ = 26 grs., and $\bar{H}$ = 5.907 grs.

3. The same natural resin was dissolved in alcohol, evaporated, subsequently treated with repeated portions of boiling water, which dissolved out benzoic acid, and then dried at 212° FAHR. It left 0.23 per cent. of ash, and

8.21 grs. (8.192 grs. pure resin) gave $\bar{C}$ = 21.76, and $\bar{H}$ = 5.23 grs.

4. The natural mixture of brown and white resins was boiled repeatedly in water, twice with dilute solutions of carbonate of soda, with the view of extracting all the benzoic acid, and again in water to separate the soda. It was then dissolved in alcohol, evaporated and dried at 212° FAHR. It left 0.3 per cent. of ash.

11.46 (11.426 grs. pure resin) gave $\bar{C}$ = 29.73, and $\bar{H}$ = 7.363 grs.

5. A portion of the resin thus treated (4.) was again boiled in a concentrated solution of carbonate of potash, washed with a dilute solution of muriatic acid, and afterwards boiled in acetic acid and well washed with water. It still retained some potash, for when burned in the air it left 1.03 per cent. of ash, being 0.73 of carbonate of potash, and the usual 0.3 per cent. of earthy matter. This quantity of carbonate of potash retained 0.26 per cent. of carbonic acid, the potash and earthy matter being together 0.77 per cent. The resin was of a reddish-brown colour, and was soluble without residue in both alcohol and ether, though, according to UNVERDORPEN*, boiling with carbonate of potash converts benzoin into two resins, one soluble and

* THOMSON'S Organic Chemistry (1858), p. 542.

the other insoluble in ether. This change, however, I am satisfied must, in UNVERDORPEN's experiment, have proceeded from some other cause than simple boiling in carbonate of potash. It may possibly have been due to the action of caustic alkali contained in his carbonate, which, as I shall hereafter have occasion to show, exercises an important modifying power over this resin at a boiling temperature, converting it into at least two resins of very different composition; or the manner of heating, or length of time during which it was boiled, may have led him to a result different from that which I have obtained. In the case of substances so susceptible of metamorphoses, as the resins will hereafter appear to be, we ought to hesitate in ascribing to errors of observation, a difference in results which may have arisen only from a slight difference in the circumstances under which the experiments, made by different chemists, were conducted. The benefit of this observation is especially due to UNVERDORPEN, who did so much, considering the state of chemistry in his time, to throw light on this interesting family of organic products.

Thus boiled in carbonate of potash,

A. 8.945 grs. (8.876 grs. pure resin) gave $\bar{C} = 23.22$, and $\bar{H} = 5.95$ grs.

B. 9.905 grs. (9.829 grs. pure resin) gave $\bar{C} = 25.905$, and $\bar{H} = 6.66$ grs.

The entire results above-detailed, allowing for the earthy matter and for the carbonate of potash, present in these last, give per cent.,

Dissolved in alcohol and heated to 212° FAHR.	Native resin heated long at 200° FAHR.	Dissolved in alcohol and treated with boiling water.	Boiled in water and in dilute carbonate of soda.	Boiled in concentrated carbonate of potash.	
				A.	B.
1.	2.	3.	4.	5.	6.
Carbon 71.14	73.06	73.43	71.95	72.59	73.13
Hydrogen 6.84	6.67	7.09	7.16	7.45	7.53
Oxygen 22.02	20.27	19.48	20.89	19.96	19.34
100	100	100	100	100	100

These results are very discordant, and on such of them as have not been repeated, perhaps much reliance ought not to be placed. There is so far an agreement among them, however, that the per centage of hydrogen goes on increasing with every successive operation to which the resin is subjected. This is quite in accordance with what ought to take place, if we suppose that additional portions of benzoic acid are removed at each step. Anhydrous benzoic acid consists of $C_{14}H_5O_3$, or calculated to C_{40} , for the purpose of comparison, it is $C_{40}H_{14.3}O_{8.37}$. In this latter formula, while the oxygen is slightly in excess, the hydrogen is many atoms less than in the resin in any of its states. The extraction of benzoic acid from the resin, must therefore necessarily increase the proportion of hydrogen in what remains, while, with the aid of the water evolved at the same time, the oxygen will be to a certain extent diminished. The resin analysed after boiling in dilute carbonate of soda (4.) still gave off benzoic acid and water, when heated in a close tube, while after further boiling in concentrated carbonate of potash it gave no sensible quantity of crystals (analyses

5. and 6.). We are to suppose, therefore, that, whether they actually existed as such in the resin or were formed by the action of the alkali, an additional quantity of benzoic acid and water was removed from the resin by the carbonate of potash. With this, the formulæ deduced from analyses 4, 5 and 6 agree, being respectively $C_{40}H_{24}O_9$, and $C_{40}H_{24}O_8$. Thus

	$C_{40}H_{24}O_9$ gives	Found by analysis 4.	$C_{40}H_{24}O_8$ gives	Found by analyses 5 and 6.	
Carbon	71.82	71.95	73.55	72.59	73.13
Hydrogen	7.03	7.16	7.25	7.45	7.53
Oxygen	21.15	20.89	19.20	19.96	19.34
	100	100	100	100	100

Without laying much stress at present on the first of these formulæ, we may from the above analyses conclude, that the benzoin of commerce, and after partial heating and boiling in water, is of very variable composition, but that after boiling in concentrated solutions of the carbonated alkalies and carefully heating, its constitution may be represented very approximately by $C_{40}H_{24}O_8$. This conclusion is confirmed by the examination of the resin which remains after the crude benzoin is boiled with quicklime.

II. Action of Caustic Lime on Resin of Benzoin.

When the benzoin resin of commerce is intimately mixed with quicklime and boiled in a large quantity of water, the resin unites with the lime, and forms a nearly insoluble compound of a beautiful purple colour, while benzoate of lime is also produced and dissolved by the boiling water. Thrown on the filter and washed for a length of time, the washings pass through of a yellow colour, which diminishes little in intensity, and is due chiefly to the solubility of the compound of a peculiar resin with the lime. I have subjected three successive portions of the crude resin to this treatment, and though I place most reliance on the results of the last portion, I insert the analyses of the other portions, as they are not without interest, in connexion both with the nature of the resin itself, and the precautions necessary to be adopted in order to obtain it of constant composition.

1. After boiling with quicklime and washing with boiling water, the purple compound was decomposed by boiling with dilute muriatic acid, and afterwards with water. It was then dried at 212° FAHR., treated with cold alcohol, and the solution evaporated at 212° FAHR. The resin was of a reddish-brown colour, and left 0.7 per cent. of ash.

8.48 grs. (8.42 grs. pure resin) gave $\bar{C} = 21.61$, and $\bar{H} = 5.595$ grs.

2. The second portion similarly treated gave a similar resin, which left, when burned in the air, 0.69 per cent. of ash, and of which when heated long at 212° FAHR.

A. 8.00 grs. (7.945 grs. pure resin) gave $\bar{C} = 20.47$, and $\bar{H} = 5.176$ grs.

B. Heated four days longer at 180° FAHR., 8.96 grs. (8.898 grs. pure resin) gave $\bar{C} = 23.21$, and $\bar{H} = 5.61$ grs.

3. The above results not being satisfactory, I prepared a larger quantity of the resin. Twelve hundred grains were boiled in an iron kettle with a large quantity of slaked lime in fine powder, in repeated portions of water, till ten or twelve quarts had passed through the filter. The solution was pale yellow to the last, muriatic acid threw down from it a resin in white flocks, which in the last solutions was smaller in quantity. This precipitate was collected for subsequent examination.

The compound with lime was, as before, of a purple colour, which became more bright and beautiful as the excess of lime was gradually removed by digestion with dilute muriatic acid. When completely decomposed by this acid, a yellow solution and a gray resinous powder were obtained. The powder was well washed, dried at 212° FAHR., and then treated with alcohol. What remained undissolved was chiefly sand and earthy matter. The alcoholic solution, evaporated and dried in a thin film at 150° FAHR., gave a resin which, after heating several hours at 212° FAHR., left 0.904 per cent. of ash, and

A. 7.36 grs. (7.29 grs. pure resin) gave $\bar{C}$ = 18.69, and $\bar{H}$ = 4.83 grs.

B. Heated further for several hours at 220° FAHR., 8.59 grs. (8.512 grs. pure resin) gave $\bar{C}$ = 22.49, and $\bar{H}$ = 5.695 grs.

C. Further heated for twelve hours at 180° FAHR., 6.94 grs. (6.875 grs. pure resin) gave $\bar{C}$ = 18.21, and $\bar{H}$ = 4.725 grs.

D. Again heated to incipient fusion ($300 \pm$ FAHR.), when the particles began to cohere, 7.53 grs. (7.46 grs. pure resin) gave $\bar{C}$ = 19.735, and $\bar{H}$ = 4.925 grs.

The following Table shows the result of these analyses of the three several portions of resin prepared by boiling with quicklime:—

First portion dried at 212° .	Second portion.		Third portion.			
	Heated at 212° .	Longer at 180° FAHR.	Heated at 212° .	Further at 220° FAHR.	Further 12 hours at 180° FAHR.	Further to incipient fusion (300° ?).
Carbon 7.97	8.71.24	9.72.13	10.70.89	11.73.07	12.73.26	13.73.15
Hydrogen 7.38	7.24	7.01	7.36	7.43	7.63	7.34
Oxygen 21.65	21.52	20.86	21.75	19.50	19.11	19.51
100	100	100	100	100	100	100

The identity of the last three results entitles us to place reliance upon them, as indicating very approximately the constitution of the resin in its normal (?) state. Comparing these with the results obtained by the analyses 5 and 6 previously given, we see that the effect of prolonged boiling with quicklime is to bring the resin into the same state as when it is boiled with concentrated carbonate of soda. In the latter analyses, however, the experimental came still nearer to the calculated numbers given by the formula $C_{40}H_{24}O_8$. Analysis 13 was undertaken in consequence of the discordance as to the amount of hydrogen between 11 and 12, and from the precautions taken,

the result of this analysis may be considered to approach very near to the true quantity.

On comparing together the columns 7, 8, 9 and 10, we see that by prolonged heating some volatile matter is given off, by which the per centage of carbon is increased; and that such is the case, appears more clearly if a portion of the resin after prolonged heating at 200° FAHR. be further heated in a close tube 50° to 100° higher. In the cooler part of the tube a colourless naphthoid fluid gradually condenses, *while the resin does not even begin to cohere*. It is difficult to pronounce with certainty that the resin is actually decomposed at this temperature, though it does seem exceedingly probable. And if we consider the coincidence of the analyses 7, 8 and 10, (the results of which are nearly identical, and for all of which the several portions of resin were heated only to 212° FAHR.,) to indicate a probable constancy of composition at this temperature, and that at a higher heat it undergoes decomposition, we should be led to adopt a formula containing nine of oxygen as representing the constitution of this resin of benzoin in its *real* normal state. Thus the formula $C_{40}H_{24}O_9$ gives

Carbon	71.82
Hydrogen	7.03
Oxygen	21.15
	100

and these numbers so far agree with the results 7, 8, 9 and 10, as to render this formula exceedingly probable. On the whole, therefore, as the best expression of the entire results, I am inclined to consider

A. That the resin obtained when the benzoin of the shops is boiled with quicklime, well washed, as above described, separated by muriatic acid, extracted by alcohol, and dried in a thin film at 212° FAHR., is represented very nearly by the formula $C_{40}H_{24}O_9$.*

B. That when this resin is further heated to incipient fusion, or for a length of time at a temperature approaching that at which it melts, it gives off a volatile liquid, and acquires the composition represented by the formula $C_{40}H_{24}O_8$.

4. It has been stated above, that when the compound of the resin of benzoin with lime was washed with boiling water, a yellow solution was obtained, which on being treated with muriatic acid gave a resinous precipitate in gray flocks. This was collected, washed, and dried at 212° FAHR. The quantity was very small, only about fourteen grains being obtained from 1200 employed in the last experiment. Dissolved in alcohol and evaporated in a thin film, it was reddish-brown, and had much the appearance of the resin already analysed. Burned in the air it left 0.6 per cent. of ash, and after being heated long at 180° FAHR., and afterwards to incipient fusion, when it gave off a perceptible quantity of a volatile oil,

6.87 grs. (6.835 grs. pure resin) gave $\bar{C} = 18.33$, and $\bar{H} = 5.67$ grs., or per cent.,

* By referring to p. 371, it will be seen that the results of the fourth analysis agree with this formula also.

	(14.)	$C_{40}H_{30}O_7$ gives	$C_{40}H_{30}O_7$ gives
Carbon	74.11	74.22	73.99
Hydrogen	9.21	8.78	9.07
Oxygen	16.68	17.00	16.94
	100	100	100

Whichever of the two formulæ in the second and third columns we adopt as the representative of the constitution of this resin, we find it very different from that of the resin of benzoin in any of the states in which we have hitherto had occasion to examine it. If we suppose it to be most nearly represented by $C_{40}H_{30}O_7$, we find that by the action of quicklime on the natural resin of benzoin there is separated or formed a small portion of a resin containing so much hydrogen as to place it *irrationally* in our artificial group, of which $C_{40}H_{32+x}O_7$ is the expression, and colophony the type. Are we, therefore, to infer that the natural resin is a mixture or compound of benzoic acid, of a resin $C_{40}H_{24}O_8$, and of another $C_{40}H_{30}O_7$, and that quicklime and carbonated alkalies are capable of separating these from each other; or that by these agents the resin is decomposed and transformed into these three compounds, which by their means are capable of being obtained from it? This question we shall be better able to consider when we have examined the action of other agents on the natural resin.

III. Action of Caustic Potash on Resin of Benzoin.

When to the solution obtained by digesting the resin of commerce in cold alcohol, a concentrated aqueous solution of caustic potash is added, a gray precipitate falls, and the supernatant liquid becomes much darker in colour. If the alkali be added drop by drop as long as any precipitate appears, the two resinous salts may be separated from each other with considerable accuracy, but if it be added in excess the precipitate readily dissolves. In this case the precipitate is again obtained by adding a fresh portion of the alcoholic solution of the resin.

1. The resinous salt thus thrown down was washed with boiling water, in which it is nearly insoluble, afterwards re-dissolved in dilute caustic potash, precipitated by dilute muriatic acid, which separated the alkali, and then washed with copious affusions of hot water. The resin was thus obtained in the form of a gray powder, which, when dry, dissolved in large quantity and without appreciable residue in hot alcohol and ether, but, from both solutions, fell in large quantity on cooling.

A. Alcohol in small quantity was digested on the whole of the resin, and the solution evaporated in a thin film, when it left in the air 1.03 per cent. of ash.

6.43 grs. (6.364 grs. pure resin) gave $\bar{C}$ = 16.74, and $\bar{H}$ = 4.293 grs.

B. A second portion of alcohol gave a solution, the resin obtained from which, after long heating at 150° FAHR., left 0.81 per cent. of ash, and

5.71 grs. (5.66 grs. pure resin) gave $\bar{C}$ = 14.615, and $\bar{H}$ = 3.66 grs.

C. Ether now digested on the mass, already treated with alcohol, gave a resin which, after long heating at 180° FAHR., left 0.39 per cent. of ash, and

5.85 grs. (5.827 grs. pure resin) gave $\bar{C} = 15.17$, and $\bar{H} = 3.575$ grs.

D. Ether was again digested on the residual resin, the solution evaporated, and the film long heated at 250° FAHR.

5.77 grs. (5.75 grs. pure resin) gave $\bar{C} = 15.01$, and $\bar{H} = 3.48$ grs.

These several results are equivalent to

	By alcohol.		By ether.	
	A (15).	B (16).	C (17).	D (18).
Carbon	72.73	71.39	71.99	72.18
Hydrogen	7.49	7.18	6.82	6.72
Oxygen	19.78	21.43	21.19	21.10
	100	100	100	100

These analyses show that the mass thus treated successively with alcohol and ether, was a mixture of at least two resins, of which the more soluble was the first taken up, and contained most hydrogen. The results of analysis A. agree very nearly with those obtained for the resin $C_{40}H_{24}O_8$, produced by the action of quicklime on the crude resin, and the portion first taken up by the alcohol may have consisted chiefly of that resin. Analysis B. again, coincides very closely with the formula $C_{40}H_{24}O_9$, which we have also formerly obtained. But these coincidences may be accidental, and it is the successive portions taken up by the ether, which give analogous results, that we are to consider as approaching nearest to the resin in its probably normal state. These results agree with the formula $C_{40}H_{22}O_9$, which gives

	Calculated.	Found (17.)	(18.)
Carbon	72.24	71.99	72.18
Hydrogen	6.48	6.82	6.72
Oxygen	21.28	21.19	21.10
	100	100	100

Besides the admixture of the resin $C_{40}H_{24}O_8$ above supposed, there may have been present in the mass, a portion also of the resin about to be described.

2. The alcoholic solution which remained after precipitating the crude resin as above described, was diluted with water, by which only a small quantity of resin was precipitated. The filtered solution was then decomposed by excess of muriatic acid, and the precipitated resin well washed with copious affusions of hot water, by which the resinous powder was not melted or made to cohere. It was then collected on the filter, dried at 212° FAHR., dissolved in alcohol, filtered, and again evaporated, and dried at a gentle heat. It left 0.2 per cent. of ash.

Four several portions of the same alcoholic solution were thus evaporated and analysed in succession:—

- A. 7.575 grs. of pure resin, gave $\ddot{C}$ = 20.28 grs., and $\dot{H}$ = 6.245 grs.
 B. 7.475 grs. of pure resin, heated at 200° FAHR. for a longer period, gave $\ddot{C}$ = 19.76 grs., and $\dot{H}$ = 6.09 grs.
 C. 7.166 grs. of pure resin still longer heated, gave $\ddot{C}$ = 18.30, and $\dot{H}$ = 5.705 grs.
 D. 7.325 grs. of pure resin, heated twenty-four hours longer than C., gave $\ddot{C}$ = 19.02, and $\dot{H}$ = 6.073 grs., or per cent.,

	A (19).	B (20).	C (21).	D (22).
Carbon	74.03	73.09	70.61	71.80
Hydrogen	9.16	9.05	8.84	9.21
Oxygen	16.81	17.86	20.55	18.99
	100	100	100	100

Though longer heated, the portion D. had not been so much changed as the portion C. There is no question of comparative purity in this instance, since all the portions were obtained from the *same* solution. The differences, if not errors of analysis, are due to the action of heat alone, and the discordant results serve to show how very much a resin may be changed by prolonged heating, at a temperature far below that at which it melts, which in the present case was never approached.

If we compare the result A. with the constitution of the small quantity of the second resin obtained by the action of quicklime (p. 375, analysis 14.), we find them to be nearly identical; and as the resin of analysis A. (19.) had been long heated at 200° FAHR., I am inclined to think that first portion to have been most nearly in the normal state of the resin, and that the differences observed in the constitution of the other portions are due to the evolution in greater or less quantity of that volatile oily product, which I have already described as given off when the resin of analysis 14 was heated to a temperature approaching that at which it began to cohere.

From this imperfect examination of the action of caustic potash on the crude benzoin, I conclude that, under the circumstances above-detailed, it was separated into benzoic acid and two resins, of which the one is represented by $C_{40}H_{22}O_9$ (analyses 17 and 18), and the other by $C_{40}H_{30}O_7$ (analysis 19).

This second resin, by prolonged heating, gives off a volatile fluid, by which its constitution is gradually altered, becoming successively $C_{40}H_{30}O_8$, and $C_{40}H_{30}O_9$. The conformity of the analytical results with these formulæ is shown by the following tabular comparison:—

$C_{40}H_{30}O_7$ gives	Found analysis (19).	$C_{40}H_{30}O_8$ gives	Found analysis (22).	$C_{40}H_{30}O_9$ gives	Found analysis (21).
Carbon 73.99	74.03	72.25	71.80	70.58	70.61
Hydrogen 9.07	9.16	8.84	9.21	8.64	8.84
Oxygen 16.94	16.81	18.91	18.99	20.78	20.55
100	100	100	100	100	100

To produce this change of constitution, it is only necessary that a carbo-hydrogen,
 MDCCCXL. 3 c

$C_{40}H_{30}$, should be given off, that is, a compound in which the elements are in the ratio of 4 to 3. Can the naphthoid fluid observed to pass off be such a compound?

That which is volatilized when the supposed resin $C_{40}H_{24}O_9$ is heated, cannot be of the same constitution, since the result is to increase the per centage of carbon, not to diminish it, as in the present case. (See analyses 7 to 13, and pp. 373 and 374.)

IV. Action of Oxide of Lead on Resin of Benzoin.

When a solution of acetate of lead in alcohol is poured into a similar solution of the resin of benzoin of commerce, a precipitate appears in comparatively considerable quantity; and though both oxide of lead and resin be largely present, no further precipitate falls, unless fresh portions of the resinous solution be added.

This remark applies to the greater number of the resins belonging to our second group ($C_{40}H_{24\pm x}O_9$). On the addition of caustic ammonia, however, a second and more copious precipitate is obtained.

1. The precipitate which falls on the admixture of the two solutions.

A portion of this salt being well washed, and afterwards dried at 250°FAHR. , was subjected to analysis.

A. 6.10 grs. left 1.455 of oxide of lead, or 23.85 per cent.; and 12.91 grs. gave $\bar{C} = 25.42$, and $\bar{H} = 5.89$ grs.

B. 4.625 grs. left 1.15 of oxide of lead, or 24.86 per cent.; and 10.535 grs. gave $\bar{C} = 20.68$ grs., and $\bar{H} = 4.725$ grs.

These results are equal to

	A (23).	B (24).	
Carbon	54.45	54.28	40 atoms.
Hydrogen	5.07	4.99	22.4 atoms.
Oxygen	16.63	15.87	8.91 atoms.
Oxide of lead	23.85	24.86	1.05 atoms.
	100	100	

The formula $PbO + C_{40}H_{22}O_9$, gives

		Per cent.
Carbon	3057.480	54.34
Hydrogen	274.549	4.88
Oxygen	900.000	16.10
Oxide of lead	1394.498	24.78
	5626.527	100

These calculated numbers agree very closely with those found by experiment, and would seem to justify us in adopting $C_{40}H_{22}O_9$, as the formula for the resin contained in this salt*. This, it will be observed, is also the formula for the resin precipitated, though in larger quantity, from the crude benzoin by caustic potash, and of which

* It is scarcely necessary to remark, that, if the resin employed contain any free benzoic acid, the precipitate here analysed would be mixed with benzoate of lead.

the experimental constitution is presented in the results of analyses 17 and 18, p. 376.

2. *The precipitate which falls on the addition of ammonia.*

A. Of this salt, washed and dried for several days at 200° FAHR.,

7.137 grs. left 2.957 of oxide of lead, or 41.41 per cent.

12.08 grs. gave $\ddot{C}$ = 18.01, and $\dot{H}$ = 4.813 grs., or per cent.,

	(25).	
Carbon	40.95	40 atoms.
Hydrogen	4.42	26.45 atoms.
Oxygen	13.22	9.88 atoms.
Oxide of lead	41.41	2.21 atoms.
	100	

The resin alone gives

Carbon	69.88
Hydrogen	7.54
Oxygen	22.58
	100

The oxide of lead is evidently not in atomic proportion, being thrown down probably in excess by the ammonia. But the resin indicates the formula $C_{40}H_{26}O_{10}$, which differs from any we have yet met with, in the analysis of the resin in its various states, as above-detailed, though other analyses, which I have not thought it necessary to insert, have given me results which would lead to a similar formula.

B. Of the salt last analysed, I decomposed a portion by boiling it with dilute muriatic acid, washed the resin well with water, dissolved it in alcohol, and dried it by a gentle heat, when

8.97 grs. gave $\ddot{C}$ = 22.79, and $\dot{H}$ = 6.136 grs.

Compared with analysis A. and with the formula $C_{40}H_{26}O_{10}$.

This result gives per cent.

	A (25).	B (26).	$C_{40}H_{26}O_{10}$ gives
Carbon	69.88	70.25	69.77
Hydrogen	7.54	7.60	7.40
Oxygen	22.58	22.15	22.83
	100	100	100

If implicit reliance could be placed on these analyses of the salts of lead, obtained directly and by the aid of ammonia, we should conclude that, by the action of oxide of lead, the resin of benzoin was separated into two resins represented respectively by $C_{40}H_{22}O_9$, and $C_{40}H_{26}O_{10}$. I am unwilling, however, myself to place implicit reliance upon them, knowing now how easily the resin undergoes decomposition by slight elevations of temperature; a fact of which I was not so well aware when these

analyses were made*. The entire subject of the action of alkalies and oxides on this resin is deserving of a complete revision, which it is my intention hereafter to undertake. The course and method of research, and the precautions to be adopted are clearly marked out by the experiments above-described, and I only leave the subject in its present incomplete state, because having made already nearly fifty analyses of this resin and its products, I may be permitted to turn my attention for a short time to some of the other members of this interesting natural family, on the constitution of which the above researches, though incomplete, tend to throw much light.

V. On the rational Constitution of Resin of Benzoin.

Benzoic acid is generally supposed† to exist ready formed in the resin of benzoin. It is obtained from the crude resin by sublimation, a gentle and uniform temperature being applied for several hours, when the acid forms beautiful crystals, amounting to about four per cent. of the weight of the resin employed. A quantity of water and of a volatile oil, having the odour of benzoin, is always (?) given off along with the acid, even when the operation is conducted in the most careful manner.

There are several circumstances which, though perhaps not decisive on the point, yet induce me to doubt whether the acid really exists ready formed, in any quantity at least, in the natural resin. A few of these I shall briefly state.

1. Heated alone at a temperature of 212° FAHR. benzoic acid is given off by the resin, it is also extracted by simple treatment with boiling water. But during this treatment the colourless resin always becomes coloured, and less fusible, and the brown shade deepens and the melting point rises, the longer it is heated even at this low temperature, till at length it becomes of a reddish-brown colour, and does not soften at a heat much above 212° FAHR. The mere removal of benzoic acid already existing in the resin, should not produce such a change in its physical characters.

It has been observed by BERZELIUS and other chemists, that when the resin of benzoin is heated, a volatile oil is given off, which, by the action of caustic potash, is transformed into benzoic acid. The removal of such an oil will account for the increased colour and diminished fusibility of the resin, while the agency of the atmosphere, when it is heated in the air, or of the elements of water when it is boiled in that liquid, or of the elements of the resin itself when it is heated alone, may produce to a certain extent the same effect as is caused more completely by the treatment with caustic potash‡. As a general observation, I have found that a deepening of the co-

* A mixture of the resin $C_{40}H_{46}O_{10}$ with benzoic acid ($C_{10}H_{14}O_2$), would give a formula approaching that of the resin contained in our first salt of lead, $C_{40}H_{46}O_7$.

† See LIEBIG'S *Chimie Organique*, I. p. 241.

‡ This result of the action of caustic potash is not confined to the oil given off by benzoin. MÜLLER has observed, that the oil of cinnamon also ($C_{20}H_{11}O_2$) is transformed into benzoic acid by repeated distillation with caustic potash, and hence he has supposed that this oil may be a compound of benzyle ($C_{14}H_9O_2$) with a carbo-hydrogen (CH), since oil of cinnamon, $C_{20}H_{11}O_2 = C_{14}H_9O_2 + 6CH$. He has not satisfactorily

lour of a resin is a consequence of incipient decomposition, and is almost always attended by the evolution of a volatile oil.

2. Dilute solutions of carbonate of soda in the cold readily dissolve crystallized benzoic acid; but trituration, or even boiling with such solutions, does not deprive benzoïn of the power of yielding this acid when subjected to heat. Concentrated solutions of the carbonated alkalies by boiling produce this effect, but they may act on the elements of the supposed oil as caustic potash does.

3. When boiled with caustic lime we have seen that a new resin is produced containing much more hydrogen; the same effect follows, and to a greater extent, by treatment with caustic potash even in the cold. This effect is most readily explained by supposing a decomposition to have taken place, by which a substance containing less hydrogen (benzoic acid) is separated, and one containing more is formed, or separated along with it.

4. It may be stated, as in some measure corroborating the above arguments, that when the resin of dragon's blood is heated for a length of time at a temperature at which it barely fuses, it gives off benzoic acid, water, and a reddish volatile oil, but is at the same time itself so much decomposed, that though retaining its red colour it becomes in a great measure insoluble in alcohol.

These reasons do not appear to me to *decide* that no benzoic acid exists in the benzoïn resin of commerce, but they render it probable, I think, that very little does so exist, at *least in a free state*, in the white varieties. The brown varieties appear to be already in some measure decomposed, and hence their colour, and the presence probably of some free acid; but all the varieties undergo further decomposition and yield more acid, when exposed to a high temperature or to the action of bases, which by their affinities *dispose* the elements to arrange themselves so as to liberate benzoic acid.

But admitting this explanation, the question remains, In what state do the elements of benzoic acid exist in the resin? Is benzoic acid present as such, but in combination with the resins, which by the action of alkalies and oxides are eliminated along with it? Are the resins analogous to the fatty bodies, and do the bases act upon each family of substances in an analogous manner, liberating from the former an oil, the analogue of glycerine (hydrated oxide of glyceryl = $C_6 H_7 O_5 + H O$) and two resins, the analogues of the oleic and stearic acids; and is this oil again, by a secondary action of the bases, converted into benzoic or some similar acid, and one or more other as yet undetected compounds? Or do the resins consist of this or an analogous acid ready formed and directly combined with one or more basic resins? Though I feel

shown, however, that no other substance is formed at the same time as the benzoic acid. BENZ. Årberättelse, 1837, p. 269.

It is interesting to observe, that in $C_{20} H_{11} O_9$, or $C_{40} H_{22} O_{18}$, we have the same ratio of the carbon to the hydrogen as in our resin $C_{40} H_{24} O_9$.

that the state of our knowledge does not justify me as yet in forming more than a conjecture on the subject, yet at present I am inclined to regard the former opinion as much the more probable. In future papers, I hope to be able to place the question in a more satisfactory point of view, by the aid of other experimental researches, which I shall then have had an opportunity of bringing before the Society.

In favour of the view of the constitution of the fragrant resins* above preferred, I would direct attention to the researches of FREMY, into the constitution of the balsams of Peru and Tolu†, in which he has detected an oily liquid (cinnameine = $C_{54}H_{36}O_8$), convertible by the action of caustic potash into cinnamic acid = $C_{18}H_8O_4$, and by chlorine, among other products, into chloride of benzyle, which water, as is well known, converts into benzoic acid. This action of potash on cinnameine he compares to that of the same base on oleine; and he considers it highly probable that the resin of benzoin, while in the balsamic state, contains an oily fluid, which by potash is convertible into benzoic acid.

FREMY has also analysed the resin of benzoin in conjunction with those extracted by him from the balsams of Peru and Tolu, and that which is obtained by the action of sulphuric acid on cinnameine.

His comparative results are as follow:—

	From balsam of Peru.	From balsam of Tolu.	From cinnameine.	Resin of benzoin.
Carbon	71.82	70.8	71.9	71.2
Hydrogen	6.78	6.1	6.5	6.5
Oxygen	21.40	23.1	21.1	22.3
	100	100	100	100

The several resins he concludes to be identical, and represents them by the formula $C_{54}H_{30}O_{12}$, which nearly coincides with our formula $C_{40}H_{22}O_9$, and gives carbon 72.4, hydrogen 6.5, and oxygen 21.1 per cent.

The above results, however, are too discordant to justify the conclusion that the resins are identical. Besides, he only gives one analysis of each resin, and describes them, in consequence of the instability of the compounds, only as tolerable approximations‡. That such is the case, indeed, is evident from his adoption of a common formula, which requires four-tenths (0.4) per cent. more hydrogen than was obtained by analysis in one of his experiments. In regard to his analysis of the resin of benzoin, it approaches nearest to No. 1. of the series given in the present paper, and may be considered in so far to confirm the statements I have had occasion to make, in regard to the slight circumstances by which the constitution of the resin may be made to vary, and the difficulty of admitting the opinion that the benzoic acid exists in it ready formed.

The portion analysed by FREMY gave only 6.5 per cent. of hydrogen, and could not

* Those represented by the formula $C_{40}H_{22}O_9$.

† Annales de Chimie et de Physique, LXX. p. 180.

‡ See his memoir, p. 204.

therefore have been deprived of all the benzoic acid it was capable of yielding; though he states that it had been purified after the method of UNVERDORFEN (see above, analyses 4, 5, 6, and 11, 12, 13.).

General Results in regard to the Resin of Benzoin.

From the experiments detailed in the present paper it appears probable,

1. That the colourless resin of benzoin is represented very approximately by the formula $C_{40} H_{22} O_9$.

2. That by the action of heat, of boiling water, or of dilute solutions of the carbonated alkalies, it is partially decomposed, giving off a volatile oil, a little water and benzoic acid, and acquires a composition represented approximately by $C_{40} H_{23} O_9$, and $C_{40} H_{24} O_9$.

3. That by the action of concentrated solutions of the carbonated alkalies, at a boiling temperature, and of quicklime in boiling water, it is resolved into benzoic acid, into one resin, $C_{40} H_{24} O_8$, which does not dissolve, and into another (the resin C. of UNVERDORFEN*?) which the salt of lime or of potash dissolves, and which is represented by $C_{40} H_{30} O_7$.

4. That caustic potash in like manner decomposes the crude resin, throwing down from the alcoholic solution a potash salt, which consists chiefly of a compound of the alkali with a resin represented approximately by $C_{40} H_{22} O_9$, but which is of a darker colour and is more sparingly soluble than the natural resin, to which the same formula has been ascribed. The supernatant solution, now of a darker colour, contains the second resin, $C_{40} H_{30} O_7$, already obtained by the action of the carbonated alkalies.

5. That by oxide of lead an analogous change is produced upon the crude resin; the precipitate which falls, on mixing the alcoholic solutions of the resin and of acetate of lead, containing by experiment $C_{40} H_{22} O_9$, and that which is thrown down by the subsequent addition of caustic ammonia, a resin $C_{40} H_{28} O_{10}$ †.

6. That all these resins are decomposed more or less easily, giving off volatile matters at a temperature much below that at which they melt, and that the results of different analyses of the same portions of resin are thus liable to be modified to a considerable extent.

It was my intention to have included in the present paper some new analyses of the resin of dragon's blood, already examined in the first part of these researches, and of the new resins produced by the action of quicklime and of oxide of lead on the several

* THOMSON'S Organic Chemistry (1838), p. 542.

† I have not adverted to the *apparent* difference between this resin and the resin $C_{40} H_{24} O_8$, that namely of the elements of two atoms of water only. I am unwilling to adopt the opinion that any of the resins contain water as a constituent, till we have some distinct facts on which to rest; but there can be no difficulty in allowing that, under certain circumstances, one resin may be transformed into another by *assimilating* the elements of one or more atoms of water.

varieties of the dragon's blood of commerce. But my remarks on the resin of benzoin have extended so much, that I think it better to reserve them for a future opportunity; I may merely state generally, that while the formula assigned to the resin contained in the lump dragon's blood is $C_{40} H_{21} O_8$, and to the drop variety after long heating at 300°Fahr , $C_{40} H_{20} O_8$, the same varieties yield by the action of quicklime and of oxide of lead, among other products two resins, represented approximately by $C_{40} H_{20} O_{10}$, and $C_{40} H_{20} O_{12}$?; that the resin of assafetida, which in Part IV. is expressed by $C_{40} H_{26} O_{10}$, gives with oxide of lead one resin, $C_{40} H_{23} O_{13}$; that the resin of jalap $= C_{40} H_{34} O_{18}$, in like manner with oxide of lead, gives a new resin, $C_{40} H_{34} O_{20}$, and the resin of guaiacum $C_{40} H_{23} O_{10}$, one represented by the formula $C_{40} H_{21} O_{11}$. The experiments from which these and other interesting formulæ are deduced, I shall have the honour of laying before the Society on a future occasion.

Having in the former papers on this subject, and in the commencement of the present, established certain approximate *irrational* formulæ for numerous resins, we have by these later results and observations been led considerably further in advance, and into a new portion of the field of inquiry.

They have opened up the question as to the *rational* constitution of the resins, and have enabled us to hazard a conjecture, in regard to what that constitution may really be.

We have seen reason from the irrational constitution of the resins to divide them into two groups characterized by unlike general formulæ, and we have observed a general analogy also in physical characters, among the members of each group. A comparison of the effect of bases on these several resins seems to confirm the propriety of this division, since the analyses of the salts of the resins, of which colophony is the type, *appear* to show that in combining with bases they undergo no change, or if any, only in regard to the number of atoms of hydrogen, and this is doubtful; while all those resins, to the salts of which reference has been made in the present paper, indicate an important metamorphosis or decomposition as the result of the action of bases. This distinction, if general, is a very wide one, and must arise from the arrangement of the constituent elements in two ways very unlike each other. Too much weight, however, is not to be attached to these apparent distinctions, as they may vanish on further investigation.

Durham, June 3, 1840.

XX. *Experimental Researches on the Strength of Pillars of Cast Iron, and other Materials.* By EATON HODGKINSON, Esq. Communicated by PETER BARLOW, Esq., F.R.S., &c.

Received April 22,—Read May 14, 1840.

WHEN we consider to what extent pillars of iron and of timber are used for the support of buildings, and reflect that there are no satisfactory rules by which to measure the strength of pillars, it becomes a matter of great importance to obtain such rules by means of experiment, and, if possible, to discover the laws on which they are founded. A feeling of this kind, heightened by the remarks of Dr. ROBISON, in his *Mechanical Philosophy*, and by the strongly-expressed opinion as to our want of such knowledge by Mr. BARLOW*, led me to wish to undertake the inquiry. I mentioned the matter, therefore, to my friend Mr. FAIRBAIRN, who, with that liberality which I have experienced from him on former occasions, at once put every means of a full investigation into my hands. He expressed a wish that I should extend the inquiry to pillars of various kinds, ancient as well as modern; and leave no part of the subject in uncertainty for want of experiments sufficiently varied and extensive. Thus freed from restraint, I endeavoured, in my wish to acquire the requisite information, to forget the expense to which I put my friend, and have made every effort to render the experiments at least ample, correct, and useful. The pillars on which the experiments were made, were mostly of cast iron, as being the material in most general use; but some were of wrought iron and steel, and others of wood.

In the earlier experiments, the pillars used were uniform cylinders, either with their ends rounded, so that the crushing force might pass through the axis, or with flat and parallel ends, so that the pillar, when placed between two perfectly parallel crushing surfaces, might have its ends completely bedded against them.

2. The pillars during the experiments were placed vertically, resting upon a flat, smooth plate of hardened steel, laid upon a cast iron shelf, made very strong, and lying horizontal. The pressure was communicated to the upper end of the pillar by means of a strong lever acting upon a bolt of hardened steel, two and a half inches diameter, and about a foot long, kept vertical by being made to pass through a hole bored in a deep mass of cast iron; the hole being so turned as just to let the bolt slide easily through without lateral play. The top of the bolt was hemispherical, that the pressure from the lever might act through its axis; and the bottom was turned

* Report to the British Association for the Advancement of Science.

flat to rest upon the pillar. The bottom of this bolt, and the shelf on which the pillar stood, were necessarily kept parallel to each other; for the mass through which the bolt passed, and that on which the shelf rested, were parts of the same large case of iron, cast in one piece, and so formed as to admit shelves at various heights, for breaking pillars of different lengths. The case had three of its four sides closed; circular apertures were, however, made through them, that the experimenter might observe the pillar without danger.

Fig. 1, Plate XIII., will show more clearly the nature of the apparatus, and the manner in which the experiments were made. Thus *AB* is the lever, about fourteen feet long, generally acting with a leverage of from four to seven; *CD* is an iron frame-work, in which the fixed end of the lever is placed, and in which it turns as on a pivot, the frame *CD* being fixed firmly in a strong heavy wall *E F*, part of which is imagined in the drawing to have been removed, to show the fixings and apparatus; *G* is the steel bolt on which the lever acts; *H* the socket through which it passes; *H I K* the iron case admitting shelves as *P*, at different heights, for pillars of different lengths not exceeding five feet; *L M* an additional part to be attached to the box *H I K*, for pillars of greater length; *N O* is one of the pillars resting upon the shelf *P*, and pressed upon by the pin *G*; *Q* is the weight, which could be removed to any part of the lever, and increased or diminished at pleasure; or entirely taken off the pillar, at any time, by means of the winding apparatus.

Experiments.

3. In order to ascertain the laws connecting the strength of cast iron pillars with their dimensions, they were broken of various lengths, from five feet to one inch; and the diameters varied from half an inch to two inches, in solid pillars; and in the hollow ones, the length was increased to seven feet six inches, and the diameter to three inches and a half. My first object was to supply the deficiencies of *EULER*'s theory of the strength of pillars*, if it should appear capable of being rendered practically useful; and, if not, to endeavour to adapt the experiments so as to lead to useful results.

4. As the results of the experiments were intended to be compared together, it was desirable that all the pillars of cast iron should be from one species of metal; and the description chosen was a Yorkshire iron, the Low Moor, No. 3. The pillars were mostly made cylindrical, as that seemed a more convenient form in experiments of this kind than the square; for square pillars generally break anglewise. The experiments, in the first table annexed, were made on solid uniform pillars, rounded at the ends, that the force might pass along the axis; and the metal was cast in dry sand, to obtain, as far as possible, uniformity in its texture. In the second table, the pillars were uniform and cylindrical, as before, but had their ends flat and at right angles to the axis. The pillars were from the same models as before, but were cast

* Berlin Memoirs, 1757, Petersburg Commentaries, 1778.

in green (moist) sand, which rendered the operation of casting less troublesome; and it was conceived that the mode of casting would make little or no difference in the strength, a conjecture which was proved afterwards to be correct. I have not given here an explanation of these or the other tables, as it is hoped they will be understood by inspection. The forms of the fractures of many of the pillars, particularly those in Tables I. and II., are given in conjunction with the drawings of the pillars in Plate XV. The position of the neutral line was sought for with great care, and is inserted in the tables wherever it could be obtained with any degree of certainty.

Conclusions from the First and Second Tables.

5. The experiments in the second table were undertaken after those in the first were nearly completed; for I found, by a trial or two, that a pillar with flat ends was much stronger than one of the same diameter and length with its ends rounded. To ascertain, therefore, the ratio of the strength in the two cases, and whether it was constant under all changes of dimension, it became necessary to make the second table to include most of the lengths and diameters of the former; and, indeed, other considerations made me reduce the lengths in it, till the pillars broke by crushing without flexure.

Taking, then, the mean breaking weights of pillars from the same models in the first two tables of experiments, and neglecting the small differences in the measured diameters of the castings, we have the ratio of the strengths as in the following abstract.

Abstract from TABLES I. and II., &c.

Pillars with rounded ends.				Pillars with flat ends.				Ratio of breaking weights of pillars with rounded and flat ends, the diameters being considered equal.
Length.	Mean diameter.	Number of experiments deduced from.	Breaking weight.	Mean diameter.	Number of experiments deduced from.	Breaking weight.	Weight which would crush the cylinder.	
inches.	inch.		lbs.	inch.		lbs.	lbs.	
60-5	.50	2	143	.51	2	487*	22430	1:3-405
60-5	.77	2	780	.77	2	2456	51130	1:3-148
60-5	.99	2	1902	.997	3	6238	85721	1:3-279
60-5	1-29	2	3707	1-29	3	16064	143508	1:2-815
60-5	1-52	2	10861	1-56	3	28962	209869	1:2-667
30-25	.50	3	539	.50	1	1662	21559	1:3-083
30-25	.77	1	2726	.77	3	8811	51130	1:3-232
30-25	.99	2	6105	1-01	4	20310	87971	1:3-326
15-125	.50	3	1904	.51	3	6764	22430	1:3-552
20-166	.767	2	6602	.777	3	15581	52064	1:2-3600
20-166	1-01	2	15737	1-022	2	31804	90074	1:2-0210
15-125	.76	3	9223	.775	4	21059	51797	1:2-2833
7-5625	.497	3	5262	.50	3	11255	21559	1:2-1389
15-125	.99	3	19752	1-000	2	40250	86238	1:2-0378
10-083	.76	3	17506	.768	4	25923	50865	1:1-4808
7-5625	.77	2	22948	.777	3	32007	52064	1:1-3947
3-7812	.50	2	15107	.52	3	24616	23319	1:1-6294

* This pillar had discs on the ends.

6. The preceding abstract contains the results of experiments with pillars varying in length, from 121 times the diameter, down to $7\frac{1}{2}$ times; and we see, from the last

column, that the ratio of the strengths of pillars, with rounded and with flat ends, is nearly constant for all pillars, from those which are the longest compared with their diameters, to those whose length is about thirty times the diameter; which is the case with the pillars $30\frac{1}{4}$ inches long, and 1.01 inch diameter; and also those of 15.125 inches long and .51 inch diameter. In all pillars, therefore, whose length is thirty times the diameter, or upwards, the strength of those with flat ends seems to be about three times as great as the strength of those of the same dimensions with rounded ends, the mean ratio being 1 : 3.167. In the pillars shorter than thirty times the diameter, the ratio is not constant: and it will be seen that it decreases when the length compared with the diameter decreases. This uniformity in all pillars down to a certain length, compared with their diameter, and the departure from it in shorter pillars, were matters which for a considerable time arrested my attention. Experiments were made upon wood and wrought iron, and the results were in accordance with these; but the reason of the deviation was first made evident by the experiments upon wrought iron, from which it appeared that short specimens of that metal became slightly crushed, and perceptibly changed in their form, by a weight which was nearly the same as that which produced a falling off in the strength of a long pillar of the same diameter. Thus it was found that a weight of 22679 lbs. produced a very obvious change in the form of a short cylinder, 1.015 inch diameter (as will be seen from the experiments further on): and a pillar of that diameter and $30\frac{1}{4}$ inches long, with the ends flat, exhibited a great falling off in strength. It was evident, therefore, that incipient crushing or derangement of the parts was the cause of the change. Cast iron does not often admit of such an alteration in its form as to be perceptible to the eye; but its strength begins to fall off with weights which differ not widely from those which deranged the form, and reduced the strength of wrought iron. I have, therefore, made the preceding abstract to include, in addition to the mean breaking weights from the first and second tables, a column containing the weights which would crush, without flexure, short cylinders of cast iron (the Low Moor, No. 3.) of the same diameters as the pillars with flat ends. These crushing weights were obtained from the experiments further on (Art. 55.), in which it was shown that prisms of this iron, perfectly bedded at the ends, and so short as not to be bent with the pressure, were crushed with a force of about forty-nine tons per square inch. The mean of my experiments gave 86238 lbs. for the crushing force of a cylinder one inch diameter; and the resistance to crushing, in the cylinders of other diameters, was calculated from this, on the supposition that the resistance is as the area of the section; which supposition was proved to be true in my Report on the strength of hot and cold blast iron*.

7. It will be seen at a glance from the preceding abstract, what portion of its crushing strength each pillar required to break it, whether the ends were rounded or flat. The pillars with flat ends, whose length was the least number of times the

* Transactions of the British Association for the Advancement of Science, vol. vi.

diameter (the ratio of the strengths of the pillars with rounded and with flat ends being uniform), required $\frac{6764}{22430}$ and $\frac{20310}{87971}$ of the crushing weights to break them.

The lengths of these pillars were thirty times their diameters, which were .51 and 1.01 inch respectively; but the pillars .777 inch diameter, and 20.166 inches long, (the length being twenty-four times the diameter), were broken with $\frac{15581}{52064}$ of the crushing weight. These last pillars, which were broken with a little less than one-third of the crushing weight, showed themselves injured by the compression, since they gave a ratio less than the mean. On the other hand, the pillars just mentioned as .51 inch diameter were broken with from one-fourth to one-third of the crushing weight; and those 1.01 inch diameter with somewhat less than one-fourth, neither of these being injured by the pressure. We may, therefore, conclude that about one-fourth of the crushing weight is the greatest load which a cast iron pillar, flat at the ends, will bear without producing a crushing or derangement of the materials, which would lessen its breaking weight; and that the length of such a pillar should be thirty times the diameter, or upwards. Pillars whose length is less than in this proportion, give the ratio of the strengths of those with rounded and with flat ends, from 1 : 3, down to 1 : $1\frac{1}{2}$, or less, according as we reduce the number of times which the length exceeds the diameter, as will be seen by the abstract.

A circumstance may be mentioned, which, perhaps, tended a little to equalize the strengths of the shortest pillars mentioned above. It became necessary to render those which were rounded at the ends more flat there, than if the ends had been hemispheres; whilst in the experiments upon pillars, whose length was greater with respect to the diameter than these, the ends were more prominent than in the hemispherical form. This change became necessary on account of the splitting of the ends in the short pillars; it having been found that the pillars whose diameter was one-thirteenth of the length or upwards, with rounded ends, failed in many instances by the ends becoming split. In these cases a portion of the rounded end of the pillar formed the base of a cone, whose vertex was in or near the axis of the pillar. This cone acting as a wedge whose sides were in the angle of least resistance, and having its vertex sharp, split and cut up the sides of the pillar, of which it formed a part*.

All the pillars in the preceding abstract became bent, and broke in the middle, as if the breaking weight had been transverse. This was the case with all the pillars tried, till those of .52 inch diameter became only two inches long, the length being less than four times the diameter.

Some of the short pillars, it will be noticed, bore more than the average crushing weight, arising from these having been cast very small, and therefore being harder and resisting with more than the average strength of the metal.

* For more detailed information on the crushing of short masses of cast iron, and the interesting forms of its fractures, see the Report in the volume of the British Association before referred to.

8. We see, therefore, that when pillars of cast iron, with flat ends, are shorter than about thirty times the diameter, the ratio of the strength of those of the same dimensions, with flat and with rounded ends, is very variable. But when the length is thirty times the diameter, or more, up to one hundred and twenty-one times, we have shown it to be nearly constant; and we may infer that the ratio would be constant, however greatly the length might exceed the diameter; since the uniformity seems to depend upon the circumstance that the weight necessary to break these long pillars by flexure, is not sufficiently great to produce much compression in them, and therefore does not alter sensibly the position of their neutral line. In this respect, cast iron has the advantage of most other metals, on account of its great power of resisting crushing, which is, on the average, from six to seven times as much as that necessary to tear it asunder*. Wrought iron, on the other hand, does not require nearly so much force to crush it, so as in a great measure to destroy its utility†, as is required to tear it asunder (Art. 60.); and therefore the ratio of the strength of equal pillars, with rounded and flat ends, becomes variable somewhat sooner in it than in cast iron, though the comparative results are the same in long pillars. The experiments on timber, and on steel, so far as they have gone, give the same results with respect to long pillars.

9. Confining our researches, for the present, exclusively to what may be termed *long cast-iron pillars*, or those whose length, in pillars with flat ends, is thirty times the diameter, or upwards, since these are but little compressed by the breaking weight, we shall obtain some interesting properties. These properties, doubtless, would be common to all rigid bodies, where the length, compared with the diameter, was so great that the breaking weight was not sufficient to diminish sensibly the power of the body to resist a transverse force. Till recently, in all inquiries respecting the strength of materials, bodies have been assumed to be incompressible; and if they really were so, the constant ratio above-mentioned, and some other properties, which I shall deduce from the results of the experiments upon cast-iron pillars, would be found in them, whatever might be their length, compared with their diameter. Some descriptions of stone may perhaps approach much nearer than cast iron to this state of ultimate incompressibility, compared with their power of resisting tension.

Strength of Long Pillars of Cast Iron.

10. We have seen, that in all long pillars, where the dimensions are the same, the resistance to crushing by flexure is about three times as great when the ends are flat as when they are rounded. This general agreement, and the near approach in point of strength, in pillars with flat ends, to those of the same diameter and of half the length with rounded ends (as may be seen by comparing the preceding abstract), led me to conceive, that if the pillars with flat ends were more firmly fixed at the extre-

* Transactions of the British Association, vol. vi., before referred to.

† The valuable experiments of Mr. BARLOW refer to a further destruction of the material.

mities, their strength would be increased, so that they would bear the same as pillars of equal diameter and of half the length with the ends rounded.

To ascertain whether this would be the case, experiments were made upon pillars $60\frac{1}{2}$ inches long, from the same models as were made in Tables I. and II., but with this addition, the pillars were now cast with strong discs upon their ends, of about double the diameter of the pillar. These discs were turned flat and perpendicular to the axis, and therefore rendered the ends of the pillar, when placed between the parallel crushing surfaces, perfectly immoveable. The results of these experiments are given in Table IV.

11. Comparing the mean breaking weights in Table IV. with those of the corresponding pillars in Table II., we shall find that pillars with discs on the ends are somewhat stronger than those without them. I will select the mean results from the second and fourth Tables, from models of the same diameter and length; and from the first Table, those from pillars of the same diameter and half the length; affixing to each result a number in a parenthesis, indicating the number of experiments the mean has been derived from.

Abstract from TABLES I., II., and IV.

Pillars with their ends turned flat. Length $60\frac{1}{2}$ inches. (Table II.)		Pillars with discs on the ends turned flat. Length $60\frac{1}{2}$ inches. (Table IV.)		Pillars with the ends rounded. Length $30\frac{1}{2}$ inches. (Table I.)	
Diameter. inch.	Breaking weight. lbs.	Diameter. inch.	Breaking weight. lbs.	Diameter. inch.	Breaking weight. lbs.
.77	2456 (2)	.51	487 (2)	.50	539 (3)
.997	6238 (3)	.775	2719 (2)	.77	2726 (1)
1.29	16064 (3)	1.00	6820 (4)	.99	6105 (2)
1.56	28962 (3)	1.28	16369 (2)	1.29	17235 (2)
		1.53	30789 (2)	1.52	32531 (3)

12. These results are, as we see, the means from a considerable number of experiments, agreeing moderately well among themselves: they show, as has been observed before, that the discs give the pillar a small increase of strength above that of a pillar with flat ends only; and the approach to equality between the strengths of the pillars with discs, and of those of the same diameter, and half the length with rounded ends, is perhaps as near as can be expected in experiments of this nature. Hence we may conclude, *that a long uniform cast-iron pillar, with its ends firmly fixed (whether by means of discs or otherwise), has the same power to resist breaking, as a pillar of the same diameter and half the length with the ends rounded, or turned so that the force would pass through the axis.*

It may here be observed, that, in comparing the strengths, I have, as before, neglected the slight differences of diameter in pillars from the same model, and supposed them all of equal diameter.

13. Of the general conclusion arrived at above, I would offer the following as an explanation. Suppose a long uniform bar, or bolt of cast iron, were bent by a press-

ure' at its ends, so as to take the form $A b c d e f B$; where all the curves $A b c$, $c d e$, $e f B$, separated by the straight line $A c e B$, would be equal, since the bar was supposed to be uniform. The curve having taken this form, suppose the points b and f to be rendered immovable by some firm fixings at those points. This done, it is evident we may remove the parts near to A and B , without at all altering the curve $b c d e f$ of the part of the pillar between b and f , and consider only that part. The part $b f$, which alone we shall have to consider, will be equally bent at all the points b , d , f . The parts c and e , too, are points of contrary flexure; consequently the pillar is not bent in them. These points are unconstrained, except by the pressure which forces them together; and the pillar might be reduced to any degree in them, provided they were not crushed or detrued by the compressing force. These points may then be conceived as acting like the rounded ends in the pillars of Table I.; and the part $c d e$ of the pillar, with its ends c and e supposed to be rounded, will be bearing the same weight as the whole pillar $b c d e f$, of double the length, with its ends $b f$ firmly fixed.



14. The theory of the strength of pillars, as given by EULER and LA-GRANGE*, and afterwards pursued by POISSON† and others, furnishes us with little information upon these subjects. According to that theory, the strength is inversely as the square of the length; or a pillar, half the length of another of the same diameter, would have four times the strength. The results of my experiments give the strength nearer to three times, as a general value for the half length in cast iron. It is, however, very variable, as will be seen by the first and second tables, unless we restrict ourselves to the longer columns.

The strength is much influenced, as has been previously observed, by the quantity of compression which the pillar sustains; and, consequently, by the position of the neutral line when the pillar is bent. The strengths, too, are different in their definition in the two cases. In the theory of EULER, the strength is estimated by the greatest weight which a pillar would bear without flexure; whilst in the present case, the estimate is formed upon the weight which would break the pillar by flexure. I have sought, on many occasions, but without success, to determine experimentally some fixed point, according to the definition of the continental theory. So far as I can see, flexure usually commences with very small weights, such as could be of little use to load pillars with in practice. It seems to be produced by weights much smaller than are sufficient to render it capable of being measured. I am, therefore, doubtful whether such a fixed point will ever be obtained, if indeed it exists. With respect to the conclusions of some writers, that flexure does not take place with less than about half the breaking weight, this, as is evident from my experiments, taken in general, could only mean large and palpable flexure; and it is not improbable that the writers were in some degree deceived from their having generally used specimens

* Acad. de Berlin, 1769; Collection Académique de Turin, Vol. 5.

† POISSON, Mécanique, 2nd edit.

thicker, compared with their lengths, than have usually been employed in this paper. Some results of the continental theory we shall, however, find of great service further on.

Pillars with one End rounded and the other flat.

15. In the first and second Tables we have the strength of cast-iron pillars, with both their ends rounded, and both flat; we will now refer to Table V., which contains the results of experiments to ascertain the strength of pillars with one end rounded and the other flat, and in some cases with discs; these results being placed between those from the pillars, with round and flat ends, as taken, with some additions, from the first and second Tables.

It has been shown, that the strength of pillars, with both their ends fixed, is to the strength, when the ends are rounded, in a constant ratio. It seems probable, therefore, that the strength, when one end is fixed and the other rounded, must be related to the results of the other cases by some very simple law. Taking the mean results from Table V. and other places, and neglecting the slight differences in diameter among castings from the same model, we have as below:

	Breaking weights in lbs.				
	143	3017	7009	7009	16493
Both ends rounded	256*	6278	13499	13565	33557
One end rounded and one flat, or with a disc ..	487	9007	20310	22475	
Both ends flat, or with discs.....					

16. The pillars in each vertical column in this abstract, are of the same length and diameter; the strengths, therefore, in the three different cases, reading downwards, are as 1, 2, 3, nearly, the middle being an arithmetical mean between the other two. It is shown, moreover, by the experiments further on, upon timber, wrought iron, and steel, that *the strength of a pillar with one end round and the other flat, is always an arithmetical mean between the strengths of pillars of the same dimensions with both ends rounded and both flat*, however the ratio of the strength of these may vary†. We see, too, by the first and second columns in the preceding abstract from Table IV., which contain the ratio of the strengths in pillars with discs, that their results are in accordance with the rest. From these facts, as well as from other evidence not adduced, I conclude that the above mean would always take place, however the fixed ends were fastened.

17. The case of pillars fixed at one end and moveable at the other, is not without its interest in practice; as piston rods of steam-engines and the rods of force-pumps are instances of the use of materials in that form, it being the same thing in effect whether the pillar be rounded at the end, or turn upon a joint there. Other instances may often be seen in practice; as where pillars are firmly based at the bottom, but

* This pillar was weakened a little by a previous experiment upon it.

† The experiments on wrought iron, show that it is, practically, the case even when the pillars are much crushed by the pressure.

through imperfect fixings, or some other cause, are capable of moving at the top. It applies, too, if I am not mistaken, to the experiments upon timber by GIRARD*, whose pillars rested upon a flat surface at the bottom, but turned with a joint at the top, or were moveable there in the direction of the length of the lever. But when the pillars were so placed as to have their least dimensions in that direction, they broke with the mean weight, as above defined, instead of the full weight, which they were expected to bear, as will be evident from a careful inspection of M. GIRARD's plates attached to the work.

18. In all the previous experiments, where the pillars were uniform and the same at both ends, the fracture took place in the middle, or very near to it. This, as might be expected, was not the case where one end was flat and the other rounded; in that case the pillar broke at some point nearer to the rounded end, the piece broken off being always a little more than one-third of the whole length. The excess, however, above one-third was so small, that I conceive this division would be absolutely that to which the material would tend, provided it were incompressible, and if the pillar were better fixed at the flat end, and more free to move at the rounded one.

With this view, two pillars, each thirty inches and a quarter long, and one inch in diameter, were formed with broad discs on one end, and rendered as nearly pointed at the other as was consistent with their bearing the pressure.

The result of the experiment upon these was this: the part broken off from one was 10·42 inches, and from the other 10·30, whilst the one-third part of the whole length was 10·08 inches. I was led to conceive the division above (one-third) not improbable, since it had been shown before, that a pillar with flat ends, or with discs upon them, bore the same as a pillar of half the length with rounded ends; and as the pillars above had a disc on one end, and were rounded at the other, they might divide themselves so that the part with the flat end might be twice as long as that with the rounded one.

The results of my experiments on wrought iron, which is the only material besides cast iron in which I have examined the matter, give the division so as to make the piece, near to the rounded end, more in excess above one-third of the whole length than in cast iron: the experiments, however, were made upon pillars too short to try the matter quite satisfactorily. This deviation, if the above views are correct, may perhaps be attributed to the greater compressibility of wrought iron than of cast, as compared with their powers of resisting tension. A better material to try it would be stone.

19. We have now seen, that when uniform pillars are so placed that one end is fixed and the other moveable, the point of greatest strain is at one-third, or a little more, of the whole length of the pillar from the moveable end. We might, therefore, economise the metal by increasing the thickness in that point, and reducing the strength as we recede both ways from it.

* *Traité Analytique de la Résistance des Solides.*

Pillars enlarged in the Middle.

20. It has been stated above, that long pillars of uniform thickness, with both ends alike, always break first, in or near to the middle: this was the case even when they had discs upon the ends, to give the utmost firmness to their fixings. It seemed evident, then, that the pillar was always too weak there. I felt, therefore, desirous to ascertain the effect of strengthening the middle of pillars; but as the ends could not be reduced at pleasure, since they would be crushed without bending, in the manner of our shortest pillars in Table II., I increased the diameter in the middle, leaving that of the ends the same; and conceiving it best to make the experiments upon pillars whose form was as simple as possible, models were made of the form of two frustums of cones, the bases of which met in the middle of the pillar, the end diameter being 1 inch, and the middle $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2 inches. The sides, therefore, were straight, and regularly tapering from the middle to the two ends. Tables VI. and VII. contain the results of the experiments, the pillars being all of the same length. In the first of these Tables, the extreme ends of the pillars were rounded, that the pressure might be through the axis; and in the second, the ends had large discs upon them, turned flat.

Table VI. shows, that in all the pillars with rounded ends, those with increased middles were stronger than uniform pillars of the same weight, the increase being about one-seventh of the weight borne by the former.

In the pillars with discs, Table VII., those with the middle but little increased, had no advantage, with regard to strength, over the uniform ones. But the pillars with the middle diameter half as great again as the end ones, bore from one-eighth to one-ninth more than uniform pillars of the same weight with discs upon the ends.

Strength of long Pillars as dependent upon their Dimensions.

21. We shall now investigate the relative strengths of long pillars, as influenced by variations in their diameter and length. From the theory of EULER, it would appear that the power of a pillar to resist *incipient flexure* is directly as the fourth power of the diameter, and inversely as the square of the length. The inquiry in this paper is with respect to the resistance of pillars to *fracture*; and, as has been mentioned before, I have not been able to find the point to which EULER's computations refer. His measures of the strength, however, seem not very widely different from those which apply to the breaking point.

Strength as dependent upon the Diameter.

22. I shall first ascertain, from the first and second Tables, the power n of the diameter to which the strength is proportional, in pillars of the same length. Comparing the resistances of the pillars whose diameters were .50 and 1.765 inches, and the length $60\frac{1}{2}$ inches, in Table I., we find that the former was broken with 143 lbs., and the latter with 15560.

$$\text{Since } \frac{1.765}{.50} = \frac{3.530}{1}$$

we have

$$1'' : 3.53'' :: 143 : 15560,$$

and

$$3.53'' = \frac{15560}{143};$$

whence

$$n = \frac{\text{Log. } \frac{15560}{143}}{\text{Log. } 3.53} = 3.718.$$

I insert below values of n , thus obtained, from the first and second Tables; and from the square pillars and those with discs, in Tables III. and IV., beginning with long pillars with their ends rounded.

23. In Table I., comparing the strength of a pillar of

.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of .77 in. diameter, gives $n = 3.928$
.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of .99 in. diameter, gives $n = 3.788$
.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.29 in. diameter, gives $n = 3.889$
.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.52 in. diameter, gives $n = 3.894$
.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.765 in. diameter, gives $n = 3.718$
.50 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.94 in. diameter, gives $n = 3.741$
.77 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.765 in. diameter, gives $n = 3.609$
.77 in. diameter, and $60\frac{1}{2}$ ins. long, with that of 1.94 in. diameter, gives $n = 3.654$
.50 in. diameter, and $30\frac{1}{2}$ ins. long, with that of 1.29 in. diameter, gives $n = 3.656$
.50 in. diameter, and $30\frac{1}{2}$ ins. long, with that of 1.52 in. diameter, gives $n = 3.687$
.77 in. diameter, and $30\frac{1}{2}$ ins. long, with that of 1.52 in. diameter, gives $n = 3.637$
.99 in. diameter, and $30\frac{1}{2}$ ins. long, with that of 1.52 in. diameter, gives $n = 3.902$
.50 in. diameter, and $15\frac{1}{2}$ ins. long, with that of .76 in. diameter, gives $n = 3.768$
.50 in. diameter, and $15\frac{1}{2}$ ins. long, with that of .99 in. diameter, gives $n = 3.425$

Mean value of $n = 3.736$

In this comparison I have excluded all pillars, the length of which was not greater than about fifteen times the diameter. In pillars shorter than in about this proportion, a great change doubtless takes place by degrees in their elasticity, and their strength is much reduced. This remark is intended to be understood only of pillars with rounded ends: in those with flat ends, the same change, we have seen, begins to take place when the length of the pillar is less than thirty times the diameter. As this change in the elasticity of pillars must be produced by the same weight (the diameter being supposed constant), the relative strength of pillars with rounded and with flat ends, to resist the change, must depend upon the *laws* that regulate their ultimate strength; and we have seen that a pillar with rounded ends will bear the same as one of double the length with flat ones. In the experiments, Table III., on square bars

60½ inches long, rounded at the ends, comparing together the strengths of the pillars whose sides are

·7716 and 1·0275, gives $n = 3·9830$;

·7716 and 1·540, gives $n = 3·6789$;

1·0275 and 1·540, gives $n = 3·4698$;

Mean $n = 3·7105$.

24. From the two preceding inquiries, as to the value of n , we see, that whether the pillar be circular or square, the power of the thickness to which the strength is proportional is nearly the same. We may therefore conclude, that the same value of n would be obtained from any other form of section.

In the values obtained from the circular pillars, which include specimens varying in length from twenty times the diameter to one hundred and twenty times, the values of n do not differ so widely, but that they may be considered as constant. They in no case rise so high as four, the power according to EULER; but in pillars, so long with respect to their diameter that the breaking weight is very small, they approach nearly to it. We may, therefore, say that four is the power to which they would arrive if the breaking weight was so small that it produced no compression in the pillar.

Long Pillars with the Ends flat.

25. We will determine the values of n , the power of the diameter to which the strength is proportional, in these pillars, in the same manner as was done in the former.

In the cylinders 60½ inches long (Table II.), comparing the strength of that of

·77 inch diameter with that of ·997, gives $n = 3·606$;

·77 inch diameter with that of 1·29, gives $n = 3·641$;

·77 inch diameter with that of 1·56, gives $n = 3·495$;

·997 inch diameter with that of 1·29, gives $n = 3·670$;

·997 inch diameter with that of 1·56, gives $n = 3·428$;

Mean $n = 3·568^*$.

The pillars of the same length, with discs upon the ends, in Table IV., if we make the same comparison of strength, give as below:

Comparing that of

·51 inch diameter with that of 1·00 diameter, we have $n = 3·922$;

·51 inch diameter with that of 1·28 diameter, we have $n = 3·820$;

·51 inch diameter with that of 1·53 diameter, we have $n = 3·775$;

·775 inch diameter with that of 1·53 diameter, we have $n = 3·568$;

·775 inch diameter with that of 1·28 diameter, we have $n = 3·578$;

1·00 inch diameter with that of 1·53 diameter, we have $n = 3·412$;

Mean = 3·679.

* In my earlier experiments the mean obtained was 3·55, and that number will be used in the computations further on in this paper.

The experiments in Table II., upon pillars shorter than these, are not in sufficient variety to enable us satisfactorily to pursue the comparison; and if we attempted one between the strengths of the short pillars in that Table, as, for instance, those of one-third, or one-fourth the length of those above, we should find the value of n very low, on account of the crippling or other great change which we have seen (Art. 6) that pillars sustain by the weight, when they are made shorter than about thirty times the diameter.

Strength as dependent on Length.

26. In order to obtain the power of the length, to which the strength of pillars of the same diameter is proportional, considering this as some inverse power x , we will determine its value from the first and second Tables, beginning with Table I., in which the lengths vary as widely as eight and sixteen to one; and we shall take the values from the whole range in that Table.

27. Here we find that a pillar of half an inch diameter and 60.5 inches long, was broken with 143 lbs., and one of the same diameter and 3.78125 inches, the one-sixteenth of the former length, required 15107 lbs. to break it. Proceeding in the manner adopted before, we have,

$$1^x : 16^x :: 143 : 15107.$$

Whence we obtain $x = 1.6807$.

In this comparison I shall assume all the pillars which were cast from the same models, to be equally thick, neglecting occasional slight differences in their diameters.

28. Pillars with their Ends rounded.

Diameters of cylinders considered equal.		Lengths of which the strengths are compared.		Values of x .	Mean values of x .
inch.	inch.	inches.	inches.		
.50	.50	60.5	and 30.25	1.914	1.799
.50	.50	60.5	15.125	1.867	
.50	.497	60.5	7.5625	1.734	
.50	.50	60.5	3.78125	1.681	
.77	.77	60.5	30.25	1.805	1.702
.77	.76	60.5	15.125	1.782	
.77	.77	60.5	7.5625	1.626	
.77	.76	30.25	15.125	1.758	
.77	.77	30.25	7.5625	1.537	1.688
.99	.99	60.5	30.25	1.682	
.99	.99	60.5	15.125	1.688	
1.29	1.29	60.5	30.25	1.595	
1.52	1.52	60.5	30.25	1.583	1.583

29. Pillars with their Ends flat.

Diameters considered equal.		Lengths of which the strengths are compared.		Values of x .	Mean value of x .
inch.	inch.	inches.	inches.		
.77	.77	60.5	and 30.25	1.843	1.625
.77	.777	60.5	20.1666	1.682	
.77	.775	60.5	15.125	1.550	
.77	.785	60.5	12.100	1.424	
.997	1.01	60.5	30.25	1.691	1.587
.997	1.022	60.5	20.1666	1.483	

30. The value of x , as exhibited in the preceding abstracts from Tables I. and II., is not constant. Taking pillars of any particular diameter, we see that x decreases according as we decrease the length of the pillar; and consequently increase the pressure necessary to break it. Thus, in pillars with rounded ends, taking those of .50 inch diameter, and comparing the strengths of those of $60\frac{1}{2}$ inches long with those of 30.25, 15.125, 7.5625, 3.78125 inches, we have $x = 1.914, 1.867, 1.734, 1.681$. In pillars with flat ends, taking those of which the diameter is .77 inch nearly, and comparing those of $60\frac{1}{2}$ inches long with those of 30.25, 20.1666, 15.125, 12.1 inches, we obtain successively, $x = 1.843, 1.682, 1.550, 1.424$. This decrease in the value of x also takes place in the comparison between the different lengths of the pillars .99 inch diameter; and it is evident that it would do so in all cases where the diameter was the same, whatever that diameter might be. The falling off in the strength of pillars, whose length is less than twenty-five to thirty times the diameter, in those with flat ends; and about one-half that length, in those with rounded ends, as before observed, is not the sole cause of this diminution in the value of x , though it is a part of it.

Indeed, we may perhaps say that both depend in some degree upon the same cause, the compressibility of the material. The increasing weight alters the position of the neutral line in the pillar, and consequently lessens the part subjected to tension. By this means the flexibility of the pillar is increased, and its resistance decreased; because this resistance depends upon the transverse strength and the power to resist flexure. The position of the neutral line, on which this variation of the strength depends, has been obtained in several of the cases of Tables I. and II.; and indeed many others.

31. In the abstract from Table I., just given, and in which the lengths vary as widely as sixteen to one, we find the highest value of $x = 1.914$, and the lowest $= 1.537$; and the mean from all the values $= 1.7117$.

The abstract from the pillars with flat ends, in Table II., is not pursued to the same extent as the former. In it, the highest and lowest values of x are 1.843 and 1.424; the mean from the whole of these being 1.612.

32. The pillars compared above comprise a much greater range of lengths than those in general use; and as the shortest pillars do not come within the simple rules applicable to the longer ones, I shall adopt 1.7 in the future calculations as an approximate value of x , applicable to most of the pillars used in practice.

33. We see from the preceding abstracts, that the values of x never rise so high as two, but approach toward it accordingly as the breaking weight becomes smaller. In the pillars .77 inch diameter and $60\frac{1}{2}$ inches long, where the length is seventy-eight times the diameter, the value of x is 1.805 in one case, and 1.843 in another; and in the pillars .50 inch diameter, and $60\frac{1}{2}$ inches long, the length being one hundred and twenty-one times the diameter, the value of x is 1.914. These facts, and the regular increase in the value of x according as the breaking weight is diminished, show that 2 is the value to which x would approximate if the breaking weight were infinitely small, or the body perfectly incompressible.

Computations of the Strength of Long Pillars by means of the preceding Numerical Results.

34. We have found that the strength of cast-iron pillars, whose diameter is the same, is inversely as the 1.7th power of the length nearly; and where the diameter differs, the strength varies according to a power of the diameter which is nearly constant. This, in cylindrical pillars, whose ends are rounded, we have found to be 3.736, and in those with flat ends 3.568, the pillars with discs upon the ends giving 3.679.

The earlier experiments gave 3.76 for the pillars rounded at the ends, and 3.55 for the flat ones; and these numbers will be retained in the following computations, whatever the form of the section may be; it having been shown that the power was nearly the same, whether the pillars were round or square.

35. As a convenient unit of comparison, we may determine the strength of a solid pillar whose length is one foot and diameter one inch, as obtained by calculation from most of the experiments in the first and second Tables.

Putting then d for the diameter of a given pillar in inches, l for its length in feet, w for its breaking weight, and x for that of a pillar one inch diameter and one foot long, we have $\frac{d^{3.76}}{l^{1.7}}$ as a comparative measure of the strength in pillars with rounded ends. Whence

$$\frac{d^{3.76}}{l^{1.7}} : \frac{1^{3.76}}{1^{1.7}} :: w : x$$

$$\therefore x = \frac{w l^{1.7}}{d^{3.76}},$$

for pillars with their ends rounded.

In the same manner, for pillars with their ends flat,

$$x = \frac{w l^{1.7}}{d^{3.55}}.$$

The results from the pillars with rounded ends in Table I. are as follow :

Diameter of pillar.	Length.		Breaking weight.	Value of x .		Mean value of x .	Error from using the mean, in parts of the value of x .
inch.	inches.	feet.	lbs.	lbs.			
·50	60·5	= 5·04166	143	30309			+ $\frac{1}{88}$
·50	30·25	= 2·5208	539	35162			- $\frac{1}{197}$
·50	15·125	= 1·2604	1904	38230			- $\frac{1}{78}$
·497	7·5625	= ·6302	5262	33263			+ $\frac{1}{269}$
·77	60·5	= 5·0416	780	32603			+ $\frac{1}{48}$
·77	30·25	= 2·5208	2726	35070			- $\frac{1}{267}$
·76	15·125	= 1·2604	9223	38360			- $\frac{1}{78}$
·76	10·083	= ·84028	17506	36547			- $\frac{1}{118}$
·99	60·5	= 5·04166	1902	30902			+ $\frac{1}{124}$
·99	30·25	= 2·5208	6105	30529			+ $\frac{1}{107}$
1·00	20·1666	= 1·6805	15737	36639			- $\frac{1}{118}$
·99	15·125	= 1·2604	19752	30401			+ $\frac{1}{108}$
1·29	60·5	= 5·04166	5707	34273			- $\frac{1}{262}$
1·29	30·25	= 2·5208	17235	31857			+ $\frac{1}{269}$
1·5275	60·5	= 5·0416	10750	34229			- $\frac{1}{462}$
1·52	30·25	= 2·5208	32531	32447			+ $\frac{1}{249}$
1·772	60·5	= 5·0416	16562	30092			+ $\frac{1}{91}$
1·95	60·5	= 5·0416	23551	29901			+ $\frac{1}{88}$

33379 lbs. = 14·901 tons.

The enumeration above includes pillars varying in length from 121 times the diameter down to 15 times, or as 8 to 1. Through this range the greatest error arising from using the mean value of x here obtained is $\frac{1}{78}$, or somewhat more than one-eighth. We shall, therefore, take 33379 lbs., or 14·9 tons, as a unit of measure for the strength of a solid uniform cast-iron pillar, of Low Moor iron, No. 3, one foot long and one inch diameter, the ends of which are rounded.

36. For solid pillars of other dimensions with rounded ends, in the same material, taking the length in feet and the diameter in inches, and using the same notation as before, we have w the strength as below :

$$w = 33379 \frac{d^{2.78}}{l^{1.7}} \text{ for the strength in lbs.}$$

$$w = 14.9 \frac{d^{2.78}}{l^{1.7}} \text{ for the strength in tons.}$$

Short Pillars.

39. The mean value 98922 lbs. would be too great, if used for calculating, by the preceding formula, the strengths of solid round pillars, which are shorter than about 30 times the diameter. I shall, therefore, insert below the values of x , from the shorter pillars in Table II.; together with the particulars of the experiments from which they were derived.

Putting these in a line with the real breaking weights, and the number of tons per square inch, upon the section of the pillars, I will endeavour to show the cause of the falling off in strength.

No. of experiment.	Diameter.	Length of pillar.		Breaking weight.	Tons per square inch, the crushing weight being 49 nearly.	Value of x from formula $\frac{w}{d^2 \cdot 25}$	Ratio of diameter to length.
	inch.	inches.	feet.	lbs.		lbs.	
1	.777	20.166	= 1.6805	15581	14.7	92224	1 : 25.95
2	.50	12.1	= 1.0083	7195	16.4	85467	1 : 24.20
3	.50	10.083	= .84028	8931	20.3	77817	1 : 20.166
4	1.022	20.166	= 1.6805	31804	17.3	71154	1 : 19.732
5	.775	15.125	= 1.2604	21059	19.9	77141	1 : 19.516
6	.785	12.1	= 1.0083	24287	22.4	46207	1 : 15.414
7	.50	7.5625	= .6302	11255	25.6	60133	1 : 15.125
8	1.00	15.125	= 1.2604	40250	22.9	59516	1 : 15.125
9	.768	10.083	= .84028	25923	25.0	49224	1 : 13.129
10	.777	7.5625	= .6302	32007	30.1	35757	1 : 9.733
11	.50	3.7812	= .3151	17468	39.7	28725	1 : 7.562
12	.52	2	= .16666	22867	48.1	11080	1 : 3.846
13	.52	1	= .08333	24616	51.74		1 : 1.923

40. The second, third, and fourth columns in this abstract give, as will be seen, the dimensions and breaking weight of the pillars, each result being generally the mean from several experiments. The fifth column gives the number of tons which the breaking weight is upon the area of the section; the sixth, the value of x , or the strength of a pillar, one foot long and one inch diameter, as calculated from each result by the formula before used (Art. 38.). The last column gives the number of times which the length exceeds the diameter.

If there were no falling off in the strength of these pillars through crushing, as before mentioned (Art. 6. 7.), we know that the value of x would be constant, and nearly equal to the mean value, 98922 lbs.; which applies, as we have seen, to cast-iron pillars flat at the ends, of which the length is not less than about 30 times the diameter. But we see, from the abstract above, that in pillars whose length is about 15 times the diameter, the value of x , which being obtained from the breaking weight must fall with it, is reduced to 46207, 60133, 59516, mean 55285; being somewhat more than 49461, the half of the general mean. In pillars whose length is 7.56 times the diameter, or a little more than a quarter of 30 times the diameter, the strength is reduced to 28725, whilst the fourth of the general mean is 24731. Pillars whose length is about 20 times the diameter, or two-thirds of 30 times, we see give the value of x 77817, 71154, and 77141, whilst two-thirds of the general mean is 65948 lbs.

All those values of x are in excess of the part of the general mean they are compared with. We might, therefore, obtain a rough approximation to the strength of short pillars by calculating, by the formula before used, the strength of the pillar; and then taking such a portion of this calculated strength as the length of the pillar is of what it would have been if it were 30 times the diameter. This easy rule would nearly in all cases give the strength somewhat under the real strength, as appears from the instances we have cited, and others we might take from the abstract.

More correct mode of estimating the strength.

41. We have seen, that when pillars are reduced in length beyond a certain extent, there is a reduction in their strength from that which is given by the rules for longer pillars; and this falling off is nearly in proportion to the reduction in the length of the pillar. Another mode of considering the matter will, it is conceived, throw some light upon the reason of the conclusion in the last article, and furnish better means of estimating the strengths.

The two last pillars, in the abstract last given (Art. 39.), broke by being crushed, all the others having been broken by flexure. One broke with 48.1 tons per square inch; and the other with 51.7. The mean result of the experiments, upon the resistance to crushing in this metal, gave 49 tons per square inch nearly (Art. 55.). Taking a mean between the results of such pillars in the abstract as have their length the same number of times the diameter nearly, we have as below, in experiments 3, 4 and 5, a pressure of 19.16 tons answering to a value of $x = 75370$ lbs.; a mean from the experiments 6, 7, 8 and 9, gives a pressure of 23.97 tons per inch, answering to a value of $x = 53770$ lbs.; and a mean between the results in the 10th and 11th experiments, gives 34.9 for the pressure per inch, and the value of $x = 32241$.

We therefore see that $\frac{19.16}{49}$ of the crushing weight reduced the value of x from 98922 to 75370; $\frac{23.97}{49}$ reduced it to 53770; and $\frac{34.9}{49}$ reduced it to 32241. In other words, when the pressure is a little more than two-thirds of the crushing weight, the strength to bear flexure is reduced to less than one-third; when the pressure is a little under half of the crushing weight, the value of x is somewhat more than half its first value; and when the pressure is less, the reduction is diminished. Comparing the weights, per square inch, with all the values of x , in the two columns, we find, amidst many anomalies, that the weights increase in some such proportion as the values of x decrease; and the latter become very small where the pressure approaches to the crushing force. Considering then the pillar as having two functions, one to support the weight and the other to resist flexure, it follows, that when the material is incompressible (supposing such to exist), or when the pressure necessary to break the pillar is very small, on account of the greatness of its length compared with its lateral dimensions, then the strength of the whole transverse section of the pillar will be employed in resisting flexure; when the breaking pressure is one-half of what would

be required to crush the material, one-half only of the strength may be considered as available for resistance to flexure, whilst the other half is employed to resist crushing; and when, through the shortness of the pillar, the breaking pressure is so great as to be nearly equal to the crushing force, we may consider that no part of the strength of the pillar is applied to resist flexure.

We may, therefore, separate these effects by taking, in imagination, from the pillar (by reducing its breadth, since the strength is as the breadth) as much as would support the pressure, and consider the remainder as resisting flexure to the degrees indicated by the previous rules (Arts. 36 and 38.).

42. Suppose then c to be the force which would crush the pillar without flexure; d the utmost pressure the pillar, as flexible, would bear to break it without being weakened by crushing (Art. 6.); b the breaking weight, as calculated by Articles 36 and 38.; y the real breaking weight.

Then, supposing a portion of the pillar, equal to what would just be crushed by the pressure d , to be taken away, we have $c - d =$ crushing strength of the remaining part, and $y - d$ the weight actually laid upon it. Whence $\frac{y-d}{c-d} =$ the part of this remaining portion of the pillar which has to resist crushing, $\therefore 1 - \frac{y-d}{c-d} = \frac{c-y}{c-d} =$ the part to sustain flexure.

But the strength of the pillar, if rectangular, may be supposed to be reduced by reducing either its breadth, or the calculated strength of the whole, to the degree indicated by the fraction last obtained. In the circle this mode is not strictly applicable; but we obtain a near approximation to the breaking weight, y , by reducing the calculated value of b in that proportion. We have, therefore,

$$c - d : c - y :: b : y,$$

$$\therefore cy - dy = bc - by,$$

whence

$$y = \frac{bc}{b + c - d}.$$

43. It has been shown (Art. 7.) that about one-fourth of the crushing weight was the utmost that a flexible pillar could be broken with, without the material being crushed, and the breaking weight reduced in consequence.

In the Table following, I will give the values of y , as deduced from all the pillars in Article 39, taking $d = \frac{c}{4}$; and, therefore, $y = \frac{bc}{b + \frac{3}{4}c}$. Before concluding this subject, I may, however, observe here, that there is a falling off in the strength of pillars, in consequence of the pressure, through all stages, from the smallest force necessary to break them to the largest, though this diminution does not become so obvious as to need correcting for, till the breaking weight is about one-fourth of the crushing weight. This reduction in strength will be shown from a comparison of the strengths of the thicker with the more slender pillars, the length being the same, the falling off always increasing with the diameter. This will be rendered evident from the decrease in the

values of n (Art. 23 to 25.). We may also see its effects in the comparison between the strengths of pillars 1.29 diameter, and between those of 1.56, in the abstract (Art. 5.). In each of these cases the pillars were of the same diameter nearly; but as the breaking weights were, from another cause, very different, the comparative strength was considerably lower than in the pillars of smaller diameter. This falling off in the strength of large pillars of equal lengths arises principally from this circumstance, that the strength to resist flexure increases as a power of the diameter somewhat under the fourth; and the resistance to crushing only as the second. Thus the pillars of greater diameter require a much greater load upon the same area of section to break them than those with smaller diameters. The position of the neutral line is therefore different, and the area of the part submitted to tension reduced; the pillar, therefore, becomes more flexible, and consequently weaker.

Some small part of this falling off in the strength of larger pillars might be accounted for by the softer quality of cast iron when cast in large masses; but other materials exhibit the same diminution of strength, and the cause above is sufficient to account for it.

Tabulated results of the formula $y = \frac{bc}{b + \frac{3}{4}c}$.

Diameter of pillar.	Length of pillar.	Value of b .	Value of c .	Breaking weight.	Calculated breaking weight from formula for y .
inches.	inches.	lbs.	lbs.	lbs.	lbs.
.50	12.1	8327	21559	7195	7328
.50	10.083	11353	21559	8931	8872
.50	7.5625	18515	21559	11255	11508
.50	3.7812	60155	21559	17468	16992
.777	20.166	16713	52064	15581	15604
.775	15.125	27005	51797	21059	21241
.785	12.1	41300	53142	24287	27043
.768	10.083	52096	50865	25923	29363
.777	7.5625	88547	52064	32007	36130
1.022	20.1666	44218	90074	31804	35631
1.000	15.125	66746	86238	40250	43797

The formula for y gives results agreeing moderately well with the strengths of pillars decreasing in length, both here and in the experiments on hollow pillars, as will be seen further on (Art. 52.).

Similar Pillars.

44. We have found the strengths of solid pillars of cast iron to vary as $\frac{d^{2.78}}{l^{.7}}$ and $\frac{d^{3.88}}{l^{.7}}$, nearly; when they are not shorter than from fifteen to thirty times the diameter, according as the ends are rounded or flat (Art. 36 to 38.).

In the research for these numbers I have been led to conclude, that, if the material had been incompressible, the 3.76 and 3.55 would each have become 4, and the 1.7 have been 2 (Art. 24. 33.). In that case the strength would have varied as $\frac{d^4}{l}$, which is

the ratio according to the theory of EULER. In similar pillars the length is to the diameter in a constant ratio. Calling the length $n d$, where n is a constant quantity, we have, in these different cases, the strength as

$$\frac{d^{2.76}}{n^{1.7} \times d^{1.7}} \quad \frac{d^{2.55}}{n^{1.7} \times d^{1.7}} \quad \frac{d^2}{n^2 d^2}$$

or, making the divisions, these become

$$\frac{d^{2.06}}{n^{1.7}} \quad \frac{d^{1.85}}{n^{1.7}} \quad \frac{d^2}{n^2}$$

In the first of these cases, the strength varies as a power of the diameter somewhat higher than the square; in the second, somewhat lower; and in the third, as the square. We may therefore conclude, that in similar pillars the strength is nearly as the square of the diameter, or of any other linear dimension*: and as the area of the section is as the square of the diameter, the strength is nearly as the area of the transverse section. The experiments in Tables I. and II. give for the strength of similar pillars, powers of their linear dimensions as below.

Diameters of pillars compared.	Length of pillars compared.	Breaking weight of pillars.	Powers of the dimensions.
Pillars with rounded ends.	inch. .497 .99	inches. 7.5625 15.125	lbs. 5262 19752
	.76 1.52	15.125 30.25	9223 32531
	.99 1.97	30.25 60.5	6105 25403
	.51 1.56	20.166 60.5	3830 28962
	.50 .997	30.25 60.5	1662 6238
	.51 1.02	15.125 30.25	6764 21844
Pillars with flat ends.	.50 1.022	10.083 20.166	8931 31804
Mean from the powers 1.865.			

In the Table above, the pillars compared were from models which were similar. I have, therefore, neglected slight deviations from similarity in the castings from these models. It appears then that the power of the lineal dimensions, according to which their strengths vary, is somewhat lower than the second.

45. If pillars be so formed as equally to resist being crushed (as shown in Art. 6.) by the breaking weight, they will be similar.

We have seen, that when pillars require a force to break them by flexure, which exceeds a certain portion of the force which would crush them without flexure, the pillar

* In deducing this conclusion, EULER remarks, that if, of two similar pillars of the same material, one be double the linear dimensions of the other, the larger will but bear four times as much as the smaller, though its weight is eight times as great. Berlin Memoirs, 1757.

sustains a considerable diminution in its power of resistance to fracture by flexure, in consequence of a partial crushing, or crippling of the material. Suppose $c d^2$ = the crushing force of the pillar (d being its diameter), or that pressure which would cause rupture in it, if it were too short to break by flexure; and $n c d^2$ that part of this pressure, which is the utmost it would, as flexible, sustain without apparent crippling or crushing. Then, since the strengths to resist fracture by flexure in pillars, with both ends rounded and both flat, were $33379 \frac{d^{276}}{l^{17}}$, and $98922 \frac{d^{235}}{l^{17}}$ respectively (Art. 36. 38.), we have these quantities each equal to $n c d^2$, in the cases where short pillars are bearing the greatest weights they can sustain without any apparent crushing. Whence,

In pillars with rounded ends,

$$33379 \frac{d^{276}}{l^{17}} = n c d^2; \therefore l = \left(\frac{33379}{n c} \right)^{\frac{1}{17}} \times d^{\frac{176}{17}};$$

In pillars with flat ends,

$$98922 \frac{d^{235}}{l^{17}} = n c d^2; \therefore l = \left(\frac{98922}{n c} \right)^{\frac{1}{17}} \times d^{\frac{135}{17}}.$$

In the former of these cases, l varies somewhat faster than as the first power of the diameter, and in the second, somewhat slower; the two showing that, in the case of pillars equally loaded to resist crushing by the weight, the length to the diameter will be nearly in a constant ratio, or the pillars must be similar.

46. *Strength of long uniform Pillars, as dependent on their weight, the length being constant.*

In general, the strength varies as $\frac{d^m}{l^n}$; where d and l are the diameter and length; and m, n , the constants on which the strength depends. If the length be the same, the strength varies as d^m ; and since the weight q of the pillar is as the square of the diameter or directly as the area, $d \propto q^{\frac{1}{2}}$; whence strength $\propto q^{\frac{m}{2}}$.

In pillars with rounded ends, $m = 3.76 \therefore$ strength $\propto q^{\frac{3.76}{2}} \propto q^{1.88}$.

In pillars with flat ends, $m = 3.55 \therefore$ strength $\propto q^{\frac{3.55}{2}} \propto q^{1.775}$.

These values were used in comparing the strengths of pillars of equal weight in Tables VI. and VII., and in other places.

It will be borne in mind that this proposition applies only to pillars above a certain length, as in Articles 36 and 38.

Hollow Pillars of Cast Iron, the Low Moor, No. 3.

47. The preceding observations have been made upon solid pillars only, as these, on account of their greater simplicity, are not only more easy to be cast than hollow ones, but present fewer difficulties in experimenting upon, and in deducing conclu-

sions. Solid pillars may be made as small as may be desired, but this is not the case with hollow ones. These require great care on the part of the moulder, and are consequently expensive. The first hollow pillars used in these experiments were cast in a horizontal position, but it was found impracticable in this way to keep the core in the centre of the casting, and therefore several of the first pillars were defective, in having one side much thicker than the other, as well as in having many air bubbles in them. These causes tended to diminish the strength of the pillars; and will account for some results in Table VIII. being lower than they otherwise would have been. The circumstance of some of these pillars being much thicker on one side than the other, gave me an opportunity of observing what falling off in strength arose from that cause, which is one to which cast-iron pillars, as used in practice, must be very liable, though not so much so as in these small experimental castings. I have therefore recorded these cases with the others, conceiving that they would be interesting to practical men; and it is gratifying to find that a matter, which would seem to destroy all confidence in a pillar, does not produce a great reduction in the strength. The cause seemed to be this: in almost every case, where pillars were much thicker, in the middle, on one side than the other, the thin side was that which was compressed: and as cast iron resists fracture by compression, with (on the average) about six times the force that it resists tension, the pillar seldom gave way by compression, and therefore bore nearly as much as it would have done if of equal thickness on both sides.

If the thick side of the pillar had become that which was compressed, which, for what I can see, was as likely as otherwise, the strength would probably have been much decreased. But the circumstance of the thin side having been so often the compressed one, must apparently have arisen from some general cause.

The difficulty of obtaining good uniform castings caused me to mention the circumstance to Mr. FAIRBAIRN, who gave orders that all the future pillars should be cast vertically, and in dry sand; and this, together with great care, produced good castings, though the core could not always be kept in the centre towards the middle of the pillar.

The greatest length of pillar to which the apparatus was adapted, was about seven feet six inches; being a length half as much again as the greatest which was used in the experiments upon solid pillars. As, in the former experiments, the five-foot pillars had, by a mistake in the commencement, been made half an inch too long, my anxiety to avoid error, however slight, caused me to have the lengths of all the shorter pillars exact subdivisions of the longer; this entailed upon all the future experiments fractional lengths, which have been introduced into the hollow cylinders, in order to make them exact multiples of the former.

The length of the hollow pillars was therefore made 7 feet $6\frac{1}{2}$ inches; and it was my wish (which was always seconded by my liberal friend Mr. FAIRBAIRN) that their diameters should be as varied as possible, both for theoretical purposes and the application of their results to practice. There were difficulties, however, which militated

against the execution of this desire. The external diameter of the pillars could not be reduced at pleasure; the internal must be large enough to admit a small hollow metallic tube, covered over with a thin stratum of loam, tied together with vegetable matter, the tube being perforated in every part with holes, and having its internal diameter large enough to allow the gas and steam to escape.

Through these causes, the smallest pillars which we could cast of the above length were $1\frac{1}{2}$ inch external diameter, and $1\frac{1}{3}$ internal. On the other hand, the experiments were bounded, in the largeness of the diameters, only by the power necessary to break the pillars. With Mr. FAIRBAIRN'S apparatus (a single lever of which the greatest multiplier was 7 or $7\frac{1}{4}$) I had never conceived it safe to apply more pressure than about 18 tons; and when an additional lever was added to this, the greatest weight used was $22\frac{1}{2}$ tons. This was in one of the experiments on hollow pillars.

Through these causes, the variation in the diameters of the longest hollow pillars was necessarily small, particularly in those with flat ends, of which the largest external diameter was about $2\frac{1}{4}$ inches, this requiring upwards of 18 tons to break it. In this, the length of the pillar was 40 times the external diameter, and therefore might be considered as representing only the longest and slenderest pillars used in practice. In this matter, however, I was not without a resource, it having been discovered, in the early part of these inquiries, that the ratio of the strengths of solid pillars with rounded ends, to those with flat ones, was nearly constant, and about as one to three; and this was the case with all pillars, from those of the greatest length, as compared with the diameter, down to a certain ratio of length, considerably shorter than we could command power to break, provided the ends of the pillar were flat.

It was therefore determined to pursue the experiments upon these hollow pillars (putting solid hemispherical caps upon the ends), increasing the diameters by small degrees (the length being the same), till I could break them no further.

In this way I was enabled to vary the external diameters from 1.74 to 3.36 inches, the former having sunk with 5711 lbs., and the latter with 50477 lbs., or $22\frac{1}{2}$ tons. In the largest pillars of this series, experiments 15 and 16., Table VIII., the length was reduced to twenty-seven times the diameter. To pursue the matter further, it now became necessary to reduce the length of the pillars, because when that was done the internal diameter could be reduced, and thus the external might be cast so small that the strength of the metal in the pillar would be overcome by the power which I had at command. Several of these pillars were, at Mr. FAIRBAIRN'S suggestion, turned outside and bored within, to make their dimensions as uniform as possible. By adopting pillars of smaller size than before, I was now enabled to render them as short, compared with the diameters, as I wished, and thus obtain specimens of most of the varieties used in practice. (See Table X.)

Tables VIII. and IX. contain the results of the experiments upon the longest hollow uniform cast-iron cylinders; with an experiment or two in each, upon solid cylinders of the same length to compare with them. The cylinders were always cast

with great care, and were either perfectly straight, or they were rendered so in the lathe, where their ends were turned flat and parallel. The pillars intended to be used with rounded ends, were made about two inches shorter than the rest, or 7 feet $4\frac{1}{2}$ inches long, in order to allow room for the rounded caps upon the ends, as before mentioned, the whole length of the pillar with caps being 7 feet $6\frac{1}{2}$ inches.

Description of the Tables.

48. The first column in the Tables on hollow cylinders contains the number of the experiments only, and needs no explanation. The second column, in giving the internal diameter of the pillar, gives it as calculated as well as measured. This was done because there was great difficulty in measuring correctly the internal diameters, which were in some degree irregular. The weight of a solid pillar of a certain diameter, and the given length, being known, from a mean of three experiments, and the weights of the hollow cylinders, together with their external diameters, being also known, from these data, the internal diameters of all the cylinders were computed; and a mean between the calculated and the observed results was taken for the internal diameter. This extra trouble was taken, as I was desirous of avoiding every possible inaccuracy in experiments which, from the expense and labour attached to them, were not likely to be soon repeated. The third and fourth columns of Tables VIII. and IX. contain the deflections caused by different weights laid upon the pillar, and the weights themselves. The fifth column contains what is denominated the breaking weight, but which means only that weight which was sufficient to overcome the greatest resistance of the pillar. This was frequently attained when a long pillar had been bent through a space perhaps not exceeding its radius. From the first experiment on long hollow pillars with rounded ends, it was evident that so little flexure of the pillar was necessary to overcome its greatest resistance (and beyond this a smaller weight would have broken it), that the elasticity of the pillars was very little injured by the pressure, if the weight was prevented from acting upon the pillar after it began to sink rapidly, through its greatest resistance being overcome.

By attending carefully to this point, the pillar was frequently saved uninjured for another experiment. The small flexure that it had got was straightened, and the rounded ends being removed, the pillar, with its flat ends well bedded against the crushing surfaces, was broken, and the results in Table IX. were recorded. The sixth columns in Tables VIII. and IX. contain the strength of a solid pillar, 7 feet $6\frac{1}{2}$ inches long, and one inch diameter, as calculated on a theoretical supposition* mentioned further on. This value is always calculated for the full length, 7 feet $6\frac{1}{2}$ inches, though some of the pillars in Table IX. were two inches shorter than that. This reduction, as well as others of a similar nature, was made on the supposition that the strength of pillars of the same thickness varies inversely as the 1·7th power of the length, as was found to be the case in solid pillars.

It had been shown, Table VI., that a solid cylindrical pillar, with rounded ends,

* POISSON, Mécanique, 2nd edition, vol. i. pp. 619 and 620.

and an enlarged middle, was stronger than a uniform pillar of the same weight. There seemed little doubt that the same would be the case in hollow pillars, or that a hollow pillar with an enlarged middle, having the metal everywhere of uniform thickness, would be stronger than a hollow uniform pillar of the same weight and thickness of metal. To form these pillars with much regularity in small experimental castings, would have been difficult; but some idea of the influence of increasing the strength of the middle, might be obtained by reducing the thickness of the uniform pillars, near to the ends, leaving the middle the same. The pillars, in experiments 7 and 8. of Table VIII., in which the ends were rounded, together with one or two others, were reduced in this manner. The pillar was reduced to half its thickness of metal, in a band two or three inches broad, near to each end, and to three-fourths of its thickness, in a similar band, about half the distance between the middle and each end. These pillars did not break in the reduced parts; and from the results it would seem doubtful, whether the strength had been in any degree lessened by the partial reduction of thickness. If this reduction had been carried uniformly on, decreasing from the ends to the middle of the pillar, leaving it the same there, the pillar would but have had three-fourths of the metal in it, and its strength would, perhaps, have been but little decreased.

Of the first ten pillars in Table IX., being those with their ends flat, one half were reduced by having portions cut away from each, as before described. These pillars never broke in the reduced parts first, except in one instance, and that was where the thickness, half-way between the middle and the ends, had been reduced somewhat more than one-fourth, which was the quantity ordered to be taken away from that part.

The calculated values in Table IX., taking a mean from the five reduced pillars, give 3060; and from the five which were not reduced, 3308; the latter being $\frac{1}{3}$ stronger than the former, leaving it doubtful whether reducing the strength toward the ends, in pillars with flat ends, effects any saving of metal. The experiments in Table VII., upon solid pillars, with discs upon the ends, show a saving, however, when the strength in the middle is much greater than toward the ends. The short pillars in Table X. will be referred to further on.

In Table XI., the first two pillars were from the same model. They were about $2\frac{1}{2}$ inches diameter in the middle, and $1\frac{1}{2}$ inch near to the ends, which had strong discs upon them turned flat, to give them a firm bearing; the pillars were hollow, as before. The weight of the former was 36 lbs., and of the latter $36\frac{1}{2}$ lbs., and their breaking weights 28667 and 27491, mean 28079 lbs. From a mean between experiments 5, 6, 7, Table IX., it appears that a hollow uniform pillar 2.02 inches external diameter (the mean of the above nearly), and weighing $36\frac{1}{2}$ lbs., required 30518 lbs. to break it. This seems to show that the uniform cylinder is the stronger*.

* This conclusion is in agreement with what may be deduced from EULER'S theoretical values of the strengths of uniform cylindrical solid pillars, and of those in the shape of a truncated cone (Berlin Memoirs, 1757); his formulæ for these being $P = \frac{a^4 D^4}{A^3 d^4} \cdot p$, and $P' = \frac{a^4 D^4 E^3}{A^3 d^4} \cdot p$.

These values are to one another, *ceteris paribus*, as D^4 to $D^4 E^3$; where D is the diameter of the uniform

The third and fourth pillars in Table XI., are two hollow pillars $2\frac{1}{2}$ inches external diameter at bottom, and $1\frac{3}{4}$ at top nearly. They tapered regularly from the bottom to the top, where there was a disc to increase the stability of fixing. The mean weight of these was 36.8 lbs., and the mean breaking weight 29488 lbs. But we have seen above, that a uniform hollow pillar 2.02 inches diameter, and $36\frac{1}{2}$ lbs. weight, would require 30518 lbs. to break it. Therefore these pillars, like the former ones, are weaker than uniform hollow pillars. Experiment 5. was with a uniform pillar having rounded ends. The section was of the form , three inches across; the pillar weighed 62 lbs., and was broken with 17578 lbs. But a uniform hollow pillar 3.01 inches diameter, and $50\frac{1}{2}$ lbs. weight (Experiment 13., Table VIII.), required 26707 lbs. to break it. Whence we see, that pillars of this form, which is nearly that of the connecting rod of a steam-engine, are very weak compared with uniform hollow cylindrical ones; the strength being as the 1.88 power of the weight nearly (Art. 46.), the hollow cylinder, if of the same weight, 62 lbs., as the pillar above, would have required 39645 lbs., or more than twice 17578, to break it.

Experiment 6. is the result from a model differing from the last in having the section of the form . This was considerably stronger than the preceding, but much weaker than a hollow cylinder of the same weight.

Experiments 7 and 8. show the strength of solid pillars when the pressure is applied to some point intermediate between the centre and the circumference; and exhibits a great falling off, from what it would have been, if the pressure had been through the axis, as in pillars from the same model in Table I.

Experiment 9. is on a pillar so fixed that the pressure is in the direction of the diagonal; and comparing its strength with that of one of the same dimensions, with rounded ends, in Table I., it is nearly the same. The strength is, therefore, only one-third of what it would have been, if the pillar had been erect, with its ends well supported, as in Table II.

The long pillars referred to in this paper will, I conceive, comprise most of the forms at present used in practice, including the best of those employed by the ancients. With respect to pillars so short as to break by crushing, experiments on twenty-eight species of timber are given at the end of the paper; and on this subject I would beg to draw the attention of the reader to my Report on cast iron, in the Sixth Volume of the British Association, before referred to. The experiments upon crushing, by M. RONDELET (Art de Bâtir), and by Mr. GEORGE RENNIE, will be known to most of my readers.

pillar, and D', E the diameters of the two ends of that in the form of a truncated cone. But if we compute the diameter of a uniform cylindrical pillar of the same length and solid content as one with unequal diameters, we shall find the uniform pillar stronger than the other, and the more so according as the inequality of the diameters of the latter is greater.

Computed Strength of Hollow Cast-Iron Cylindrical Pillars.

49. In solid cylinders of the same material, the strength to resist breaking varies according to some constant power n of the diameter; the length of the pillar and form of the ends being the same. Thus, strength $\propto D^n$, where D is the diameter. In cylinders with rounded ends, my experiments give $n = 3.76$ nearly; and in those with flat ends, $n = 3.55$ nearly.

According to the theory of EULER, the strength of a hollow cylinder, to resist incipient flexure, varies as the difference of the fourth powers of the radii, or of the diameters, external and internal, or as $D^4 - d^4$, where D and d are the external and internal diameters†.

It appeared probable that this ratio, modified by changing the indices to the results of the experiments upon solid pillars, might agree with those upon hollow ones. This was tried, and, with great satisfaction, found to answer.

We have, therefore,

Strength as $D^{3.76} - d^{3.76}$, in pillars with rounded ends;

Strength as $D^{3.55} - d^{3.55}$, in pillars with flat ends.

To determine the strength of a solid pillar of a given length and one inch diameter, calling that strength x , and putting w for the breaking weight of a hollow pillar of the same length whose external and internal diameters are D and d , we have

$$D^{3.76} - d^{3.76} : 1^{3.76} - 0^{3.76} :: w : x.$$

Whence

$$x = \frac{w}{D^{3.76} - d^{3.76}} \text{ for rounded ends.}$$

$$\therefore x = \frac{w}{D^{3.55} - d^{3.55}} \text{ for flat ends.}$$

By these formulæ, the strength of a solid cylinder, 1 inch diameter and 7 feet $6\frac{3}{4}$ inches long, has been calculated from all our longest hollow cylinders, and inserted with the results of the experiments from Tables VIII. and IX.

The value of x thus obtained from each of the experiments, must, it is evident, be nearly constant, if the assumption respecting the indices be correct.

I have extracted these values from the different experiments and given them in the following Table, and also a fraction indicating the magnitude of the difference between the result from each experiment and the general mean, and consequently the error which would arise from calculating by the general mean.

* POISSON'S Theorem gives P the strength, $= \frac{\pi^3 a (g'^3 + g^3) (g'^3 - g^3)}{4 l^3}$, where l = the length, $\pi = 3.1416$,

a = a quantity, which is equivalent to the modulus of elasticity in weight per unit of section; and g' , g the external and internal semi-diameters. But $(g'^3 + g^3) (g'^3 - g^3) = g'^6 - g^6$; and all the other quantities are constant, according to the assumption in the text.

† POISSON, Mécanique, vol. i. p. 620.

Pillars with rounded ends.		Pillars with flat ends.	
Values of x .	Error from using general mean.	Values of x .	Error from using general mean.
834.37	$+\frac{1}{24}$	2973.70	$+\frac{1}{129}$
933.13	$-\frac{1}{322}$	3031.50	$+\frac{1}{193}$
826.20	$+\frac{1}{77}$	2968.70	$+\frac{1}{124}$
903.28	$+\frac{1}{308}$	3586.90	$-\frac{1}{29}$
808.21	$+\frac{1}{23}$	3573.80	$-\frac{1}{23}$
1041.70	$-\frac{1}{93}$	3290.30	$-\frac{1}{318}$
917.62	$+\frac{1}{606}$	3214.80	$-\frac{1}{1129}$
996.24	$-\frac{1}{156}$	2988.30	$+\frac{1}{131}$
1123.50	$-\frac{1}{59}$	3099.00	$+\frac{1}{201}$
989.95	$-\frac{1}{173}$	3115.50	$+\frac{1}{44}$
949.48	$-\frac{1}{207}$	3207.70	$-\frac{1}{1409}$
1059.50	$-\frac{1}{23}$		
819.46	$+\frac{1}{73}$		
895.02	$+\frac{1}{227}$		
880.11	$+\frac{1}{127}$		
1026.60	$-\frac{1}{129}$		
927.86	$+\frac{1}{1603}$		
1005.30	$-\frac{1}{138}$		
784.90	$+\frac{1}{53}$		

General mean 932.76.

General mean 3186.38.

50. The last value of x , in pillars with rounded ends, was from a pillar so short as evidently to have been a little crushed by the breaking weight, a matter which we have seen weakens a pillar (Art. 6.).

If the results from this experiment had been omitted, the general mean would have been increased from $932\frac{3}{4}$ to 941, and the fractional errors somewhat lessened. Another cause of irregularity in some of these pillars has been before alluded to (Art. 47.).

The mean values of x , above, represent the strength of a solid pillar one inch diameter, and 7 feet $6\frac{3}{4}$ inches long, as obtained by calculation, on the preceding principles, from pillars whose length was thirty times the diameter, or upwards, in those with flat ends, and half that length or more, in those with rounded ends.

It was shown (Art. 31, 32.), that when the lateral dimensions of pillars are the

same, the strength varies inversely as the 1.7th power of the length, as a sort of general average. Adopting this number, and calculating by it the strength of a pillar one foot long, from the strength of one 7 feet $6\frac{1}{2}$ inches long, we have the strength of solid pillars one foot long and one inch diameter,

In pillars with rounded ends 29074 lbs. = 12.979 tons ;

In pillars with flat ends . 99318 lbs. = 44.338 tons.

The mean strengths of pillars one foot long and one inch diameter, as obtained (Art. 35 to 37.) from the experiments on solid pillars, are 33379 lbs. and 98922 lbs. respectively ; which, in pillars with flat ends, is pretty nearly in agreement with that above. But the defective specimens in the first hollow pillars, with rounded ends, has caused the number to be 29074, whilst the solid cylinders gave 33379 lbs.

51. Taking the numbers above, as deduced from the hollow pillars, we have for the strength of hollow cylindrical pillars in general,

$$29074 \frac{D^{2.76} - d^{2.76}}{l^{1.7}}, \text{ in pillars with rounded ends ;}$$

$$99318 \frac{D^{2.33} - d^{2.33}}{l^{1.7}}, \text{ in pillars with flat ends.}$$

In using these formulæ, which answer for solid cylinders when $d = 0$, it must be borne in mind that they do not apply to pillars whose length is less than about thirty times the external diameter when the ends are flat, nor to those of less than half that length when they are rounded.

Short hollow Pillars.

52. When pillars are shorter than as above, we have seen (Art. 6.) that there is a falling off in their breaking strength, on account of a change being produced in the material through the great weight necessary to break them. This falling off has been attempted to be accounted for (Art. 41.), and a formula given by which the strengths of pillars, however short, could be calculated from the theorems used for long pillars, by means of the crushing strength of the body, the latter being shown to be an element in the resistance of pillars to fracture by flexure.

This formula for short pillars (Art. 43.) is

$$y = \frac{bc}{b + \frac{1}{4}c}$$

where b is the strength of the pillar, as calculated by the rules for long pillars (Art. 51.), and c the weight which would be required to crush the pillar without flexure.

Table X. contains the results of experiments upon thirteen pillars varying in length from twenty-four times the external diameter down to less than eight times. In this table, the deflections were not observed, as they were very small, and required much care ; and there was considerable danger in observing them, for the pillar usually broke, with violence, into many pieces. They were made, however, with great care :

the castings were good, and were, as before remarked, frequently bored within and turned on the outside, to ensure uniformity as much as possible.

The values of b , c , and y , are calculated and inserted in the Table. I will extract from it the real and calculated breaking weights, that the reader may see how far they agree.

Real breaking weight.	Calculated breaking weight.	Difference in parts of real breaking weight.
33679	32331	$-\frac{1}{249}$
32867	31790	$-\frac{1}{202}$
35302	36501	$+\frac{1}{294}$
31195	28764	$-\frac{1}{128}$
30383	30291	$-\frac{1}{339}$
41751	40128	$-\frac{1}{257}$
27135	29449	$+\frac{1}{1173}$
25511	26191	$+\frac{1}{273}$
25105	26273	$+\frac{1}{2149}$
26729	27364	$+\frac{1}{236}$
27135	30663	$+\frac{1}{727}$
37285	40257	$+\frac{1}{123}$
34037	31750	$-\frac{1}{148}$

Power of Cast-iron Pillars to resist long-continued Pressure.

53. In all the previous experiments, the pillars were broken without any regard to time, and an experiment seldom lasted longer than from one to three hours. There might, therefore, be considerable doubt upon the minds of many persons whether the results obtained would be consistent with those which would arise from long-continued pressure.

At my suggestion, therefore, Mr. FAIRBAIRN had the apparatus (fig. 2. Plate XIV.) erected, by which pillars might be permanently loaded. Four pillars from the same model were used; they were each placed vertically upon a horizontal iron plate on the ground, and pressed upon at the top by means of a pin, kept vertical by passing through an iron collar surrounding a hole bored in the horizontal timber at the top of the frame. The bottom ends of these pins were slightly concave, that they might press, without slipping, upon the top of the pillars, which were rounded at the ends, whilst the top of the pin was rounded, that it might be acted upon uniformly by the square flat plate which rested upon it, and which by means of the suspending rods at the corners supported the weight.

Mr. FAIRBAIRN intends that the results of these experiments shall continue to be observed in conjunction with his interesting experiments upon the effect of long-continued pressure upon horizontal bars.

The results obtained up to the present time are below, as taken from Mr. FAIRBAIRN'S register.

Uniform pillars of Low Moor Iron, No. 3, each six feet long and one inch diameter, rounded at the ends, and placed vertical with the following weights on each.

Date of observation.	Temperature FAHR.	1st Experiment. Weight of pillar 14 lbs. 13 oz. Permanent load 448 lbs.	2nd Experiment. Weight of pillar 14 lbs. 13 oz. Permanent load 784 lbs.	3rd Experiment. Weight of pillar 14 lbs. 11 oz. Permanent load 1120 lbs.	4th Experiment. Weight of pillar 14 lbs. 13 oz. Permanent load 1456 lbs.
		Deflections. inch.	Deflections. inch.	Deflections. inch.	Deflections. inch.
1839.					
July 5.	72	-018	-03		
6.	68			-215	-250
8.	69	-01	-02	-230	-275
16.	63	-01	-023	-235	-310
23.	64	-01	-02	-235	-320
Aug. 13.	63	-01	-023	-235	-395
Nov. 7.	50	-01	-03	-24	-825
Dec. 9.	39	-01	-025	-243	-955
1840.					
Feb. 14.	50	-01	-025	-245	Broke about 19th or 20th Decem- ber, 1839.
April 27*.	63	-01	-025	-365	
June 6.	61	-01	-025	-380	
Aug. 3.	74	-01	-030	-395	
Sept. 14.	55	-01	-025	-380	

A pillar of the same dimensions, and cast at the same time as those above, was broken with 1500 lbs. laid gradually upon it. Hence, supposing the strengths to be the same, we see that the pillar in the fourth experiment above, had borne $\frac{1456}{1500}$, or $\frac{97}{100}$ of its breaking weight, between five and six months; though the deflection had been regularly increasing from the first. I would therefore infer, that the short or long time employed in making an experiment has little influence upon its result.

In concluding my inquiries into the strength of cast-iron pillars, I shall give the tensile, compressive, and transverse strengths, together with the specific gravity of the iron made use of, to serve as data for other researches.

Tensile Strength of Low Moor Iron, No. 3, or resistance which it would offer to a direct force tending to tear it asunder.

54. The castings were of the same form as were used for this purpose in my Report on the Strength of Cast Iron†. The form of the section torn asunder was ; and the force was in a line perpendicular to this, and passing through the centre. The

* The experiments of this and the subsequent dates were inserted during the printing of the paper.

† Transactions of the British Association, vol. vi.

ends of the castings were made very strong and rigid, and they were perforated, so that links passing through them, to tear the casting asunder by, should act directly through the axis.

1st exp. area of section 1.5330 } square ins. Breaking weight 21219 }
 2nd exp. area of section 1.5470 } Mean 1.540 Breaking weight 23551 } Mean 22385,
 or strength, per square inch, 14535 lbs. = $6\frac{1}{2}$ tons nearly.

Compressive Strength of the Iron used above, or that which would crush it without Flexure.

55. The first four experiments on this matter were on rectangular masses, cut out of the pieces torn asunder, the sides being rendered smooth and perpendicular to each other. The other are from the shortest cylinders in Table II.

No. of Experiment.	Area of section in inches.	Height of specimen.	Crushing weight.	Crushing weight per square inch.
	sq. in.	inches.	lbs.	lbs.
1	Rectangles } 1.00 x .25 = .25	.50	25923	Mean 25923
2		.50	25923	
3		1.00	24355	Mean 24551
4		1.00	24747	
5	Cylinders 32 inch diameter } -21237	1.00	23963	Mean 24616
6		1.00	24747	
7		1.00	25139	
8		2.00	23035	Mean 22867
9		2.00	22699	
				103692
				98204
				115911
				107675

When bodies are crushed, as above, they give way by a wedge sliding off in an angle dependent upon the nature of the material; and in cast iron the height of this wedge is about $1\frac{1}{2}$ the diameter, or thickness of the base of the wedge. If the body to be crushed is shorter than would be sufficient to admit a wedge of the full length to slide off, then it would require more than its natural degree of force to crush it; because the wedge itself must either be crushed, or slide off in a direction of greater difficulty. If, on the other hand, the height of the body to be crushed be much greater than the length of the wedge, then the body will sustain some degree of flexure, and fracture will be facilitated in consequence.

To determine the crushing strength of the iron above used, I shall, for the reasons just given, take the results from those specimens which are but little longer than the wedge.

Taking, therefore, a mean from the results of the rectangles half an inch high, and the cylinders one inch, we have,

From the former 103692 } Mean 109801 lbs. = 49.0183 tons per square inch.
 From the latter 115910 }

Whence we obtain 86238 lbs. = 38.499 tons, for the weight which would crush a

short cylinder one inch in diameter, since the crushing force is as the area of the section, as I have shown*.

Transverse Strength of the same Iron (Low Moor, No. 3.).

56. To determine this, the results from two square bars placed upon horizontal supports, four feet six inches asunder, and broken by weights suspended from the middle, are given below.

First Experiment. Depth of bar 1·002 inches. Breadth of bar 1·004 inches.			Second Experiment. Depth of bar 1·005 inches. Breadth of bar ·996 inches.		
Weight.	Deflection.	Deflection. Load removed.	Weight.	Deflection.	Deflection. Load removed.
lbs.	inch.	inch.	lbs.	inch.	inch.
28	·069	·002 ?	28	·060	
56	·145	·006	56	·141	·005
112	·307	·020	112	·321	·030
224	·677	·07	224	·725	
336	1·143	·17	336	1·230	
392	1·413	·26	392	1·550	
448	1·742	·38	448	1·910	
461	broke.		473	broke.	

The weights were increased toward the last by about 7 lbs. at a time. The modulus of elasticity in lbs. per square inch, obtained from the deflection caused by 112 lbs. is,

$$\left. \begin{array}{l} \text{From the first experiment } 14,251,950 \\ \text{From the second experiment } 13,585,530 \end{array} \right\} 13,918,740 \text{ Mean.}$$

Specific Gravity of the same Iron.

57. This, from the results of six experiments, is as below :

- 7122 from cylinders three-fourths of an inch diameter.
- 7135 from cylinders three-fourths of an inch diameter.
- 7034 from cylinders three-fourths of an inch diameter.
- 7090 from cylinders half an inch diameter.
- 6977 from cylinders half an inch diameter.
- 6952 from a hollow cylinder.

Mean 7052.

Pillars of Wrought Iron, Steel, and Timber.

58. The experiments upon these, which are given in Tables XII. and XIII., are similar in their objects to those upon cast iron, but much more limited in their extent. They were made, indeed, principally to confirm views which presented themselves during the experiments upon cast-iron pillars.

* Transactions of the British Association, vol. vi. before alluded to.

The following abstract contains the lengths, lateral dimensions, and breaking weights of the three kinds of pillars tried.

Length.		Pillars with both ends rounded.		Pillars with one end flat, and the other rounded.		Pillars with both ends flat.	
		Diameter.	Breaking weight.	Diameter.	Breaking weight.	Diameter.	Breaking weight.
Wrought iron.	inches.	inches.	lbs.	inches.	lbs.	inches.	lbs.
	90½	1-017	1808	1-02	3355	1-02	5280
	60½	1-015	3938	1-03	8137	1-02	12990
	30½	1-015	15480	1-015	21355	1-015	23371
	30½	1-015	15480	1-015	21187 disc.	1-015	25387 disc.
	15½	1-005	23535	1-005	26227	1-005	27099
Steel.	29-95	87	10516	87	20315	87	26059
Timber.	60½	Side of square. 1-75	3197	Side of square. 1-75	6109	Side of square. 1-75	9625

The pillars in each horizontal line in this abstract are of equal length, and nearly of equal diameter, the only essential difference being in the form of their ends. Taking the longest pillars, those of 90 $\frac{1}{2}$ and 60 $\frac{1}{2}$ long, the strengths are

	Ends rounded.	Ends rounded and flat.	Ends flat.
In iron . . .	1808	3355	5280
In iron . . .	3938	8137	12990
In timber . . .	3197	6109	9625

The strengths in these three cases are, therefore, as one, two, three nearly, the middle being an arithmetical mean between the other two. These results are a corroboration of those from cast-iron pillars (Art. 16.). We see, too, from the wrought-iron pillars 30 $\frac{1}{2}$ and 15 $\frac{1}{2}$ inches long, as well as from those of steel, which appear to have been slightly crushed by the weight (Art. 6.), that this ratio one, two, three, does not obtain in short pillars, but that the difference of the strengths of the three forms of pillars becomes less, according as the number of times which the length of the pillar exceeds the diameter decreases. But whatever may be the ratio of the strengths of pillars with rounded ends to those with flat ones, the strength of those with one end rounded and one flat, is nearly an arithmetical mean between the strengths of the other two, as will be seen from the numbers below.

Mean from strengths of pillars, with both ends rounded and both flat.	Strengths of pillars, one end rounded and one flat.
lbs.	lbs.
3544	3355
8464	8137
19426	21355
20434	21187
25317	26227
18287	20315
6411	6109

59. We have seen in the preceding abstract from Table XII., that the longest wrought-iron pillars of the three classes there considered, have their strengths as one, two, three nearly; but that the shorter pillars, those of $30\frac{1}{4}$ inches long, or less (the diameter being 1.015 inch nearly), differ much less in their relative strengths. These in the $30\frac{1}{4}$ inch pillars being

Ends round.	Ends round and flat.	Ends flat.
15480	21355	23371
15480	21187	25387

The second and third of these numbers in either series are much less than twice and three times the first number, which was a mean from three experiments.

We see, therefore, that these second and third numbers are the results from pillars which were affected by some cause that did not reduce the strength of the pillars of equal diameter and length, which were broken by the first weight, 15480 lbs. For it will be seen further on, that this first weight was as great as is in accordance with the results from the longer pillars.

60. To determine the cause of this anomaly, which had first been exhibited in the experiments upon cast iron, and afterwards was found to take place in wrought iron, steel, and timber, I felt to be very difficult. The experiments upon cast iron offered no satisfactory explanation of the matter, for it usually changes but little in form before fracture. Wrought iron appeared, therefore, to be a better material for exhibiting the cause.

Three small cylinders of the same iron as that in Table XII. were therefore formed. They were each exactly $2\frac{1}{2}$ inches long and .62 inch diameter, their ends being turned flat and perpendicular to the axis; they were subjected to compression with their ends well-bedded, and after bearing certain weights they were tried by a gauge which had exactly fitted them before. The results are in the table below.

No. of Experiment.	Weight laid on.	Weight per square inch.	Reduction in length.	Remarks.
	lbs.	lbs. tons.	inch.	
1	6222	20610 = 9.2	.07	No alteration, or, if any, extremely small.
1	7342	24319 = 10.9	.015	
1	8462	28028 = 12.5	.02	
2	12444	41218 = 18.4	.04	Diameter sensibly increased, cylinder not bent. Diameter increased from .62 to .63 inch, slightly bent.
3	18667	61830 = 27.6	.16	

We see, from the above, that 6222 lbs. produced no sensible change in the cylinder .62 inch diameter, but that 7342 lbs. and 8462, particularly the latter, which was equal to $12\frac{1}{2}$ tons per square inch, produced very obvious changes.

Since the resistance to crushing are as the areas, the former of these two values would give 19677 lbs., and the latter 22679 lbs., for the pressures which would produce an equal alteration in a bolt 1.015 inch diameter; which is the diameter of the

bars upon which most of the experiments on wrought iron were made. But we have seen (Art. 59.) that 21187 lbs., and 21355 lbs. produced a great change in the strength of the pillars $30\frac{1}{2}$ inches long; it was, therefore, obvious that incipient crushing was the cause of the great falling off in the strengths of these pillars, and indeed of those in all the preceding experiments (Art. 6.); and a knowledge of this fact prepared me for attempting to adapt the formula used for long pillars to the case of short ones (Art. 41.).

61. It was shown (Art. 12.) from the experiments upon cast iron, that a uniform pillar, with its ends flat, had the same strength as one of equal lateral dimensions, and half the length, with the ends rounded. Making a similar comparison between the wrought-iron pillars, in Table XII., or in the preceding abstract (Art. 58.), we obtain an approximation to the same result; and that even when the pillars, from their shortness, are much crushed by the breaking weight, which we have seen was the case with the shortest wrought-iron pillars.

Strength of Pillars of Wrought Iron and Timber, as dependent upon their dimensions.

62. On this subject I have laboured under considerable difficulty, for want of experiments of a sufficiently comprehensive character to furnish all the data that were required. The complete determination of the constants for the purpose would require experiments upon pillars, whose lengths, compared with their diameters, were nearly as various as those upon cast iron in this paper.

I trust, however, that the experiments in Tables XII. and XIII., and the analogies derived from the results on cast iron, will supply the deficiencies so far, as, in some measure, to meet the wants of practice.

Length.—To find the inverse power of the length to which the strength of wrought-iron cylindrical pillars, of a constant diameter, is proportional, I shall follow the mode used for cast-iron pillars (Art. 26. 27.); and confining the inquiry to pillars sufficiently long not to have been crushed (Art. 6. 60.) with the breaking weight, we have as below:

Lengths of which the strengths are compared.				Description of pillar.	Inverse power of the length.
ft.	ins.	ft.	ins.		
7	6½	2	6½	Rounded ends.	1.9546
7	6½	5	6½	Rounded ends.	1.9199
7	6½	5	0½	Flat ends.	2.2203
					} Mean 2.0316.

Whence it appears that the strength is as the inverse square of the length nearly.

Diameter.—To find the power of the diameter, or of the side of a square, to which the strength of wrought-iron pillars of a given length is proportional. For this purpose we have, from Table XII., the following results:

In the pillars 2 feet $6\frac{1}{2}$ inches long, rounded at the ends, from a mean between three experiments, one of .52 inch diameter had its greatest resistance overcome with

1260 lbs; and from a mean between three other experiments, a pillar of the same length and 1·015 inches diameter had its greatest resistance overcome by 15480 lbs.

Since $\frac{1\cdot015}{\cdot52} = \frac{1\cdot9519}{1}$, we have, putting n for the power, $1^n : 1\cdot9519^n :: 1260 : 15480$.

Whence reducing, and taking the logarithms, we obtain $n = 3\cdot75073$, which is nearly the same as the mean from the cast-iron pillars with rounded ends (Art. 23.).

Computed Strength of Wrought-iron Pillars long enough not to be crushed, as in Art. 59. and 60., by the weight which would overcome their greatest resistance.

63. We have seen, from the last article, that the strength of cylindrical pillars whereof the length is constant, varies nearly according to the same power of the diameter as that in cast-iron ones. But where the diameter is constant, the strength is inversely as the square of the length, nearly.

Whence if, in round or square pillars, we put d for the diameter, or side of the square, l for the length, b the breaking weight, a , a' constant quantities, and adopt the powers of d , which were used for cast iron, we shall have (Arts. 36. 38.)

$$b = \frac{a d^{3\cdot75}}{l^2},$$

in pillars with rounded ends;

$$b = \frac{a' d^{2\cdot55}}{l^2},$$

in pillars with flat ends.

From the pillars in Table XII. we obtain as below:

	ft. ins.	lbs.
From those 7	$6\frac{3}{4}$ long, with rounded ends,	$a = 97049$
From those 5	$0\frac{1}{2}$ long, with rounded ends,	$a = 94648$
Mean value of $a = 95848$		

	ft. ins.	lbs.
From those 7	$6\frac{3}{4}$ long, with flat ends,	$a' = 281464$
From those 5	$0\frac{1}{2}$ long, with flat ends,	$a' = 307770$
Mean value of $a' = 299617$		

Here the length is taken in feet, and the diameter in inches.

Timber.

64. To find n the power of the diameter, or of the side of a square, to which the strength is proportional, the length being constant, and the pillar so long as not to be crushed (Arts. 59. 60.) with the breaking weight. For this purpose Table XIII. will supply us with the results of six experiments upon pillars of Dantzic oak, 46·1 inches long. Whence it appears that a pillar 1·02 inch square was broken with a mean weight = 1754 lbs., and one 1·50 inch square with 7888 lbs.

Here $\frac{1.50}{1.02} = \frac{1.470}{1}$, $\therefore 1'' : 1.47'' :: 1754 : 7888$. Reducing gives $n = 3.902$.

Whence the strength is nearly as the fourth power of the side of the square.

I made no experiments to ascertain the inverse power of the length to which the strength is proportional in timber. The great flexibility of such long and slender pieces as would have been necessary to give sufficient variety in their length,—and for the length of the shortest to be a sufficient number of times the thickness, that it would not be sensibly crushed by the breaking weight,—convinced me that it would be as well to seek for this power hypothetically, as to endeavour to obtain it by experiments, which would probably be unsatisfactory.

I therefore assumed (after trying some other hypotheses less successfully,) the strength of timber to be as $\frac{d^4}{l^3}$, which is the simple conclusion of EULER.

Whence $b = \frac{a d^4}{l^3}$, where the constant a must be obtained from experiment, for any particular kind of wood.

Dantzic Oak.

The experiments in Table XIII. upon square pillars of this wood flat at the ends, give as below :

1st. From a mean of the results of four experiments, a pillar $60\frac{1}{2}$ inches = 5.04166 feet long, and 1.75 inches square, required 9625 lbs. to break it. Whence, taking the length in feet and the lateral dimensions in inches, we have (in the formula $b = \frac{a d^4}{l^3}$) $b = 9625$, $d = 1.75$, $l = 5.04166$ $\therefore a = \frac{b l^3}{d^4} = 26085$.

2nd. From a mean of three experiments upon pillars 46.1 inches = 3.84166 feet long, and 1.50 inches square, the breaking weight was 7888 lbs.; which gives a , obtained as above, = 22999 lbs.

A mean between these two values of a is 24542 lbs.; whence $b = 24542 \frac{d^4}{l^3}$.

Here the length is in feet, the side of the square in inches, and the weight in lbs.; and the rule is only applicable to cases where the pillar is in length so many times the thickness that it is not crushed, as in Articles 6. and 59, by the breaking weight. These remarks apply to the following cases :

Red Deal.

The results from two experiments upon square pillars of this wood, each four feet ten inches long, and two inches square, Table XIII., give $b = 17511 \frac{d^4}{l^3}$; the different values being as above.

LAMANDÉ'S Experiments upon Oak (from TREDGOLD'S Carpentry).

These experiments were upon square pillars of different lengths, varying as 1, 2, 3, and the sides of their squares as 2, 3, 4. This writer has, in most instances, given four experiments or more to determine the breaking weights of pillars of each size. The longest pillars, compared with their thickness, in this series are 6'375 feet long, and 2'126 inches square, the length being about thirty-five times the side of the square; and the average breaking weight from four experiments was 7769 lbs. We therefore get $a = \frac{b l^3}{d^4} = 15455 \text{ lbs.}$, whence $b = 15455 \frac{d^4}{l^3}$. Further on, I shall endeavour to compute the results of LAMANDÉ'S experiments.

Short Pillars of Timber.

65. We have seen that pillars of cast iron, wrought iron, and timber, follow in a great measure the same laws as to their strength (Arts. 5. 58.). In these different materials, pillars with rounded ends have their strength in a constant ratio to that of those with flat ends. This, however, only applies to pillars whose length is so many times the diameter or thickness, that they are not sensibly crushed by the breaking weight.

My experiments have not shown what part of their ultimate crushing weight pillars of timber will bear without suffering such a diminution of their strength, from this cause, as to need correcting for, as was done in estimating the strength of short pillars of cast iron (Art. 41.). In that metal there appeared to be a slight falling off in the strength of even the longest pillars, which I accounted for by the shifting of the position of the neutral line, but it was not such that the results of the general formulae then used (Art. 36 to 38.) needed modifying; nor was there shown a defect in comparing the breaking weight of the pillars with rounded ends with those with flat ones, till the breaking weight was about one-fourth of the weight which would have crushed the whole pillar without flexure (Art. 6.).

It seems probable, from the experiments in Table XIII., that timber will bear, without much reduction of the breaking weight from crushing, considerably more than one-fourth of the ultimate crushing weight; for the pillars 1'75 inch square and 60½ inches long, with flat ends, exhibited no reduction in comparison of strength with those with rounded ends, though the mean breaking weight of the former was more than one-third of the weight which would have crushed the whole section. It may, however, be remarked, that the circumstance of a pillar with flat ends bearing upwards of three times as much as one of the same diameter with rounded ends, does not prove that the former had not its breaking weight in some degree reduced by crushing, since both descriptions of pillars were considerably compressed. In the absence of other information, therefore, I shall in calculating the strengths of short pillars of timber by the formula $y = \frac{bc}{b+c-d}$ (Art. 42.), suppose d , as in cast iron,

to be one-fourth of c , the crushing weight of the section. We have, therefore, as before,

$$y = \frac{bc}{b + \frac{1}{4}c}$$

where b = the computed value from the general formulæ for long pillars of different kinds of woods in the last article, and y that for short ones.

If there were no fixed pressure at which pillars in breaking suffered a marked diminution of their strength, but that there was a regular falling off with all weights from the least necessary to break a long pillar up to such as would crush it, then d might be taken = 0, and the formula would be

$$y = \frac{bc}{b + c}$$

where b would have to be obtained from experiments upon the longest pillars only, and this formula must be used for all others but them. We see that the strength of short (and perhaps long) pillars to resist fracture by flexure depends upon their resistance to crushing. Before attempting, therefore, to calculate the strengths of the short pillars broken by LAMANDÉ, we must know the crushing strength of the French oak, which fortunately is given by RONDELET*, who states that its strength, from a mean between his experiments, is 6336 lbs. per square inch. Whence we are enabled to obtain an approximation to the value of c , the crushing weight of the pillars which LAMANDÉ made use of.

66. The following table contains the results of his experiments upon short pillars computed by the formula for y , from the value of b , deduced (Art. 64.) from his longest and slenderest pillars, which we may consider not to have been materially reduced in their strength by crushing, and which are placed the first in the Table.

* *Traité de l'Art de Bâtir*, tome 1, p. 232, edit. 1838.

LAMANDÉ'S Experiments upon Square Pillars of Oak.

Length of pillar.	Side of square.	Value of δ deduced (Art. 64.) from 1st experiments below.	Value of c computed from RONDELET'S experiments.	Breaking weight.	Calculated breaking weight from formula $y = \frac{\delta c}{\delta + \frac{1}{4}c}$
feet.	inches.	lbs.	lbs.	lbs. Mean.	lbs.
6-375	2-126		28638	$\left\{ \begin{array}{l} 7244 \\ 7484 \\ 8492 \\ 7878 \end{array} \right\}$ 7769	
4-25	2-126	17480	28638	$\left\{ \begin{array}{l} 11844 \\ 12225 \\ 13565 \\ 12458 \end{array} \right\}$ 12523	12850
2-125	2-126	699205	28638	$\left\{ \begin{array}{l} 15631 \\ 21296 \\ 19993 \\ 21060 \end{array} \right\}$ 19495	21908
6-375	3-18	38888	64072	$\left\{ \begin{array}{l} 26939 \\ 28987 \\ 23929 \\ 33048 \\ 36902 \end{array} \right\}$ 29961	28659
4-25	3-18	87498	64072	$\left\{ \begin{array}{l} 43639 \\ 36865 \\ 36205 \\ 28182 \end{array} \right\}$ 36223	41358
2-125	3-18	349993	64072	$\left\{ \begin{array}{l} 50958 \\ 50958 \end{array} \right\}$ 50958	56207
6-375	4-25	124069	114444	$\left\{ \begin{array}{l} 64090 \\ 59373 \\ 54062 \\ 65608 \end{array} \right\}$ 60783	67646
4-25	4-25	279156	114444	$\left\{ \begin{array}{l} 100755 \\ 85998 \\ 73238 \\ 96368 \end{array} \right\}$ 89090	87532
2-125	4-25	1116620	114444	$\left\{ \begin{array}{l} 95262 \\ 105826 \\ 94476 \\ 88442 \end{array} \right\}$ 96001	106275

The breaking weights above were calculated on a supposition that the oak resisted with a force of 6336 lbs. per square inch. But Mr. BARLOW* states that oak, according to RONDELET (in an early edition of his work), required from 5000 to 6000 lbs. per square inch of base to crush it. If I had adopted these measures of the strength, instead of the former, the calculated values would have been a little lower, and the

* Treatise on the Strength of Timber, &c.

value of d (Art. 65.) might have been assumed somewhat higher. The experimental results of GIRARD from pillars of oak* were calculated, but they agree so little among themselves, that the results of those which were consistent with one another are not given. The reason of the irregularity was attempted to be explained in the early part of this paper (Art. 17.).

Other computations, upon the shortest pillars in Table XIII., agree moderately well with the results of experiment.

Crushing Strength of Timber.

67. To facilitate computations, as to the strength of short pillars of different kinds of wood in the manner above, or otherwise, I shall insert below, from my own experiments, the crushing strength per square inch of some of the descriptions in frequent use, the force being applied in the direction of the fibre.

Description of Wood.	Strength per square inch in lbs.
Alder	6831 to 6960
Ash	8683 to 9363
Baywood	7518 to 7518
Beech	7733 to 9363
American birch	 11663
English birch	3297 to 6402
Cedar	5674 to 5863
Crab	6499 to 7148
Red deal	5748 to 6586
White deal	6781 to 7293
Elder	7451 to 9973
Elm	 10331
Fir (spruce)	6499 to 6819
Hornbeam	4533 to 7289
Mahogany	8198 to 8198
Oak (Quebec)	4231 to 5982
Oak (English)	6484 10058
Oak (Dantzic, very dry)	 7731
Pine (pitch)	6790 to 6790
Pine (yellow, full of turpentine)	5375 to 5445
Pine (red)	5395 to 7518
Poplar	3107 to 5124
Plum (wet)	3654
Plum (dry)	8241 to 10493
Sycamore	7082
Teak	 12101
Larch (fallen two months)	3201 to 5568
Walnut	6063 to 7227
Willow	2898 to 6128

The results in the first column were in each case a mean from about three experiments upon cylinders of wood turned to be one inch diameter, and two inches long, flat at the ends. The wood was moderately dry, being such as is employed in making models for castings. The second column gives the mean strength, as before, from similar specimens, after being turned and kept drying in a warm place two

* *Traité Analytique de la Résistance des Solides.*

months longer. The lengths of the latter specimens were, in some instances, only one inch, which reduction would increase the strength a little. But the great difference frequently seen in the strength, as given by the two columns, shows strongly the effect of drying upon wood, and the great weakness of wet timber, *it not having half the strength of dry*. The strength of short columns of the same material I have shown to be directly as the area of the section*. This seems easy to conceive, as bodies of the same nature always become crushed by sliding off in an angle, which is nearly constant; the height of the wedge, which would slide off, being in timber usually about half the diameter, or thickness of the specimen.

Relative Strength of Long Pillars of Cast Iron, Wrought Iron, Steel, and Timber.

68. To compare the strengths of pillars, of the same size, in the different materials used in the preceding experiments, I have computed, by the rules used for cast iron (Art. 36-38.), the strength of a pillar, of the same diameter and length, in each body, taking the results from the longest pillars, in order that they may not be crushed (as described in Art. 6.) by the breaking weight. The relative strengths are as below:

Calling the strength of cast iron 1000, we have for wrought iron 1745, cast steel 2518, Dantzic oak 108·8, red deal 78·5. These numbers, except the last, are all computed from the pillars with rounded ends.

* Transactions of the British Association, vol. vi.

TABLE I. (Continued.)

Length.	Diameter.	Mean Diameter.	Deflection of middle of pillar.	Corresponding weight.	Breaking weight.	Mean from breaking weights.	Remarks.
inches.	inch.	inch.	inch.	lbs.	lbs.	lbs.	
60.5	1.94	1.94	bent.	3355	22811	22811	Weight of pillar 44 lbs.
60.5	1.97	1.96	-02	7386	25403	24291*	Weight of pillar. { 47 lbs. } Mean 46 lbs. 12 oz. { 46 lbs. 8 oz. } T : C :: 150 : 42, or 153 : 43.
			-07	12970			
			-20	19943			
			-23	21035			
			-28	22127			
			-37	23219			
			-50	24311			
			-52				
			-60	24857			
			-03	12287			
			-05	14839			
			-11	17391			
			-19	19943			
			-20	21219			
			-35	22395	23179		
			-48	22787			
30.25	.50	.50	bent.	248	526	539	Broke $2\frac{1}{2}$ inches from middle. Broke near the middle. Broke $\frac{1}{2}$ inch from middle.
			-03	360			
			-15	472			
			-02	304			
30.25	.50		-09	472	535		
30.25	.50				556		
30.25	.77	.77	-02	1717	2726	2726	For form of fracture, see <i>f</i> . Plate XV.
			-07	2054			
			-10	2390			
30.25	.99	.99	-04	2745	6105	6105	T : C :: 76 : 23. { T : C :: 78 : 21. This bent apparently in different directions. For the forms of fracture, see <i>c d s</i> . Plate XV.
			-13	4985			
			-02	3641			
			-07	4985			
30.25	1.29	1.29	-01	12287	17515	17235	Neutral line well-defined. T : C :: 96 : 34; in another case 95 : 32. { T : C :: 105 : 24; small flaw in tensile part. For the forms of fracture, see <i>a b</i> . Plate XV.
			-03	13563			
			-04	14839			
			-07	16115			
			-08	12287			
			-10	13563			
			-12	14839			
			-21	16115			
30.25	1.52	1.52	-04	22619	32419	32531	T : C :: 99 : 51. T : C :: 101 : 52. T : C :: 110 : 43.
			-06	25867			
			-12	30739			
			-07	22619			
30.25	1.53				34638		
30.25	1.51				30536		
20.1666	1.00	1.01			15737	15737*	{ Weight 4 lbs. 3 oz.; T : C :: 63 : 67. Weight 4 lbs. 5 oz.; T : C :: 69 : 37. For form of fracture, see <i>A</i> . Plate XV.
20.1666	1.02				15737		

TABLE I. (Continued.)

Length.	Diameter.	Mean Diameter.	Deflection of middle of pillar.	Corresponding weight.	Breaking weight.	Mean from breaking weights.	Remarks.
inches.	inch.	inch.	inch.	lbs.	lbs.	lbs.	
20-1666	.785	.767	.....	.....	7855	6602*	{ Weight 2 lbs. 8½ oz. Weight 2 lbs. 6 oz.
20-1666	.75		.....	.....	5950		
15-125	.50	.....	.....	1689	.....	.....	{ Neutral line well defined. T : C :: 39 : 11. T : C :: 39 : 11. In this experiment the deflection was taken as the pillar was bending.
			.....	1801	.....	.....	
			.....	1913	.....	.....	
15-125	.50	.....	.....	1997	1997	.....	
			.....	1801	.....	.....	
			.....	1857	1857	.....	
15-125	.50	.....	.....	1353	.....	.....	
			.....	1689	.....	.....	
		.50	.....	1801	1857	1904	
15-125	.77	.....	.....	.....	10138	.....	T : C :: 48 : 29.
15-125	.76	.....	.....	.....	9746	.....	T : C :: 53 : 23.
15-125	.75	.76	.....	.....	7786	9223	T : C :: 49 : 26. For the forms of fracture, see g. Plate XV.
15-125	.99	.....	.....	.....	20163	.....	T : C :: 57 : 42.
15-125	.99	.....	.....	.....	19239	.....	T : C :: 60 : 39.
15-125	.99	.99	.....	.....	19855	19752	T : C :: 60 : 39. For forms of fracture, see i, j, k. Plate XV.
10-083	.76	.76	.....	.....	16683	17506	{ The two first failed by the ends becoming split, by a conical wedge forming at them.
10-083	.76		.....	.....	16683		
10-083	.77		.....	.....	19152		
7-5625	.51	.....	.....	.....	6188	.....	T : C :: 31 : 20.
7-5625	.49	.....	.....	.....	4578	.....	T : C :: 32 : 17.
7-5625	.49	.497	.....	.....	5019	5962	T : C :: 34 : 15.
7-5625	.77	.77	.....	.....	23893	.....	T : C :: 35 : 42.
7-5625	.77		.....	.....	22003	22948	T : C :: 41 : 36. These pillars were split at both ends. For fractures, see l, m. Plate XV.
3-7812	.50	.....	.....	.....	15233	15107	{ In these two experiments the area compressed seemed to have been greater than the extended area. The ends were split by the pressure. For form of fracture, see n. Plate XV.
3-7812	.50	.50	.....	.....	14981		

By the letters T, C are to be understood the versed sines or depths of the neutral line on the surfaces submitted to tension or compression; and the ratio T : C is that of those versed sines or depths. The neutral line is not, strictly speaking, a straight one, but a curve; the dimensions are, however, so adapted that it may be considered as a straight line.

The pillars marked with an asterisk were cast after the others, and from the same description of iron, but probably a different sample; some of them were cast in green (moist) sand, too, whilst all the rest of the pillars were cast in dry sand.

In all cases, except otherwise mentioned, the pillars broke nearly in the middle, both in this Table and the following one.

Results of Experiments on the Resistance of Solid Uniform Cylinders of Cast Iron to a Crushing Force.

TABLE II.—Low Moor Iron, No. 3, cast in green sand, Plate XV. No. 1, C. Ends of cylinders turned *flat* and parallel to each other, and the pressure caused by the approach of two parallel surfaces, between which the cylinder was placed, its ends perfectly coinciding with them.

Length.	Diameter.	Mean Diameter.	Weight.	Deflection of middle of pillar.	Corresponding weight.	Breaking weight.	Mean from breaking weights.	Remarks.		
inches.	inch.	inch.	lbs. oz.	inch.	lbs.	lbs.	lbs.			
60.5	.51	.51	{ 3 4 3 5 1/4 }			{ 483 491 }	487	These two had discs two inches diameter upon the ends; all the rest had the ends turned flat, and were without discs.		
60.5	.51									
60.5	.77	.77	7 5 1/2	.07	1162	2316	2456	{ After bearing 2036 it bent in another direction.		
				.11	1812					
				.22	2036					
				.30	2260					
60.5	.77			.06	1588					
				.08	1812					
				.10	2036					
				.13	2260					
				.17	2484	2596				
60.5	.99	.997	11 8	.05	4123	5971	6238			
				.12	5467					
				.21	6139					
				.30	6475					
60.5	1.01			.05	4123					
				.14	5467					
60.5	.99			.04	4123	5932				
		.....	.....	.10	5467					
60.5	1.30			.10	11235	16527	16064			
		.....	.....	.11	11627					
		.....	.....	.14	12411					
		.....	.....	.16	13195					
		.....	.....	.19	13979					
		.....	.....	.24	14763					
		.....	.....	.30	15547					
		.....	.....	.47	16331					
60.5	1.29	1.29	19 11	.15	11217					
		.....	.....	.22	13177					
		.....	.....	.26	13961					
		.....	.....	.37	14745					
				.45	15137	15333				
60.5	1.28		20 0			16331				

TABLE II. (Continued.)

Length.	Diameter.	Mean Diameter.	Weight.	Deflection of middle of pillar.	Corresponding weight.	Breaking weight.	Mean from breaking weights.	Remarks.
inches.	inch.	inch.	lbs. oz.	inch.	lbs.	lbs.	lbs.	
60.5	1.55	1.56	28 10	.13 .15 .21 .48 .62	21857 23481 25105 26729 27135	27135	28962	{ Broke immediately after the deflection was taken. <

TABLE II. (Continued.)

Length.	Diameter.	Mean diameter.	Weight.	Mean weight.	Breaking weight.	Mean breaking weight.	Ratio T : C.	Remarks.
inches.	inch.	inch.	lbs. oz.	lbs. oz.	lbs.	lbs.		
20-1666	.51	.51	1 1½	1 1½	3830	3830		
20-1666	.51		1 1¼		3830			
20-1666	.78	.777	2 9	2 8½	16701	15581	45 : 33	The first broke in two-pieces near to the middle, and near to one end; and a piece was split off the other end, at the neutral line. The other two broke nearly in the same manner. For figure of fracture, see g, Plate XV.
20-1666	.78		2 8½		15357			
20-1666	.77		2 7½		14685			
20-1666	1.03	1.022	4 6	4 5½	39007	31804	56 : 46	Broke in two places near middle; both ends cracked at neutral line. For figure of fracture, see o, p, Plate XV.
20-1666	1.015		4 5		31601			
15-125	.51	.51	14	13½	6512	6764	32 : 19	
15-125	.51		13½		7016			
15-125	.51		13		6764			
15-125	.79	.775	29½	29 5/16	21179	21059		
15-125	.77		29		22363			
15-125	.76		28½		19003			
15-125	.78		29		21691			
15-125	1.00	1.00	3 4	3 4	39112	40250		For form of fracture, see r, s, Plate XV.
15-125	1.00		3 4		41388			
12-1	.50	.50	10½	10½	7279	7195	3 : 2	
12-1	.50		10		6943			
12-1	.50		10		7363			
12-1	.78	.785	1 7½	1 7½	25355	24287	39 : 39	
12-1	.79		1 8		24043			
12-1	.79		1 8½		23875			
12-1	.78		1 7½		23875			
10-083	.50	.50	8½	8½	8287	8931	13 : 12	
10-083	.50		8		8623			
10-083	.50		8½		9883			
10-0833	.78	.768			27491	25923	1 : 1	These generally broke in several pieces; but always in the middle by bending. There was, however, usually a wedge formed about the centre which tended to split the pillar there.
10-0833	.77				25531			
10-0833	.76				25531			
10-0833	.76				25139			
7-5625	.50	.50	6½	6½	11479	11255	12 : 13	
7-5625	.50		6		11143			
7-5625	.50		6½		11143			
7-5625	.78	.777	14½	14 5/16	33225	32007	4 : 5	There was a good deal of doubt respecting the neutral line; but somewhat more than one-half was compressed. For fracture, see t, u, v, Plate XV.
7-5625	.78		14½		31601			
7-5625	.77		14½		31195			
3-7812	.50	.50			17795	17468	20 : 30	These broke in the middle by bending as before, but they generally showed a short ridge or wedge in the centre, as mentioned above.
3-7812	.50				17935			
3-7812	.50				16675			
2	.52	.52			23035	22867		The first bent and slid off in A B. The other bent and cracked half across in the middle.
2	.52				22699			
1	.52	.52			23963	24616		Broke by wedge, about three quarters of an inch high, sliding off in the direction A B.
1	.52				24747			
1	.52				25139			



Further remarks on Table II. The ratio T : C shows the position of the neutral line, as described in the notes to Table I. The two pillars that stand first in this Table had discs upon their ends, two inches diameter, turned flat; and the weight of the pillar, as set down, is that without the discs. These were added on account of the smallness of the diameter, .51 inch, as compared with the length, $60\frac{1}{2}$ inches, to give the ends a firmer bearing; but in all other instances, the pillars in this Table were without discs.

The forms of fracture *o*, *p*, *q*, &c. Plate XV., referred to in these Tables, and the marks upon the pillars over them, show the manner, and into what number of pieces, some of the specimens broke, though the figures are not drawn to a scale. The exact dimensions of these pillars will be obtained from the Tables.

TABLE III.—Rectangular, or Square Uniform Pillars of Low Moor Iron, No. 3, $60\frac{1}{2}$ inches long, rounded at the ends. Plate XV. No. 3, A, B, C.

Dimensions of section.	Mean dimensions, or side of equal square.	Weight of pillar.	Mean weight.	Deflection.	Weight causing the deflection.	Breaking weight.	Mean breaking weight.	Remarks.
inch. inch. .77 × .77 .77 × .78 .77 × .77	inch. }.7716	lbs. oz. 9 3½ 9 3½ 9 3½	lbs. oz. } 9 3½	inch.	lbs.	lbs. 1251 1307 1251	lbs. } 1269	Broke by bending in direction of diagonal. Broke by bending in direction of diagonal.
1.02 × 1.04	}.10275	16 7	} 16 3½	-.01 ? -.02 -.04 -.08 -.16 -.23 -.43	1118 1364 2036 2708 3380 3716 4052	4164	} 3968	Broke three inches from middle, by bending in direction of diagonal, a wedge .25 inch deep separating from corner, the diagonal being 1.45 inches long. Broke as before, depth of wedge .28 inch.
1.03 × 1.02		16 0		-.01 ? -.02 -.05 -.09 -.22 -.45	1118 1364 2036 2708 3380 3716			
1.54 × 1.52	}.1540	35 9	} 35 15½	bent -.01 -.02 -.05 -.17 -.33	3355 5467 7483 10843 14203 15861	16673	} 16127	A B, the neutral line, the triangle being compressed. B C = .35 inch. After bearing 14203 lbs. it was unloaded and returned to .01 inch. A B, the neutral line. A C, = .45 inch.
1.54 × 1.56		36 6		bent -.015 -.02 -.11 -.23 -.35 -.44 -.52	2141 4465 6481 11169 13563 14461 14909 15357			

The Table above may be considered as a supplement to Table I., the object of the experiments in this being, to ascertain whether square pillars of different diameters varied in their strength according to the same laws that round ones do, a matter which will be examined into further on.

TABLE IV.—Strength of Solid Uniform Cylindrical Pillars of Low Moor Iron, No. 3, 60½ inches long, with discs upon their ends to prevent them turning. Plate XV. No. 2, fig. 3.

Diameter of pillar.	Mean diameter.	Weight of pillar.	Deflection.	Corresponding weight.	Breaking weight.	Mean breaking weight.	Remarks.
inch. -51 } -51 }	inch. -51	lbs. oz.	inch.	lbs.	lbs. 483 } 491 }	487	
-78 } -77 }	-775	8 9 7 10	-16 -23 -26 -31 -35 -44 -61	1089 1617 1841 2065 2289 2513 2737	 2926 } 2513 }	 2719	{ After bearing the first weight it had taken a set of about -01. Broke ¼ inch from middle, at a slight flaw. Broke 1½ inch from middle.
1-00 } -99 } 1-00 } 1-00 }	1-00	12 12 12 9 12 10 12 9	-06 -15 -34 -48 -04 -06 -10 -21	4123 5467 6811 7147 7315 4095 5439 6111 6783	 7483 } 7117 6907 5815 }	 6830	Broke in middle. Broke ¾ inch from middle, and the disc at one end was split.
1-28 } 1-28 }	1-28	21 5 21 8	-01 ? -05 -11 -22 -30 -36 -51 -01 ? -02 -18 -25 -38 -62	2381 4973 11169 14405 15301 15749 16197 2749 5437 13797 14805 15813 16317	 16421 } 16369 } 16317 }	..... ..... ..... ..... ..... ..... ..... ..... ..... ..... ..... ..... .....	After bearing 4973 it was unloaded and returned to -00. { Broke 2 inches from middle and near one end. T : C :: 101 : 28. After 5437 it returned to -00. { Broke in about a minute, 1½ inch from middle, and near one end. A wedge showed T : C :: 91 : 36.
1-53 } 1-53 }	1-53	29 4			32007 29571 }	30789	Broke in middle T : C :: 116 : 37. { This was a little bent, and probably weakened by making straight.

TABLE V.—Uniform Pillars of Low Moor Iron, No. 3, with one end rounded and one flat, placed between others, with both ends rounded and both flat.

Description.	Length of pillar.	Diameter.	Mean diameter.	Weight of pillars.	Deduction.	Weight causing the deflection.	Breaking weight.	Mean breaking weight.	Remarks.
Both ends rounded. Plate No. 1, A.	30½	79	78	3 13			2953	3017	
Both ends rounded. No. 1, A.	30½	78		3 12	.....	.....	3372		
Both ends rounded. No. 1, A.	30½	77		.....	.....	.....	2726		
One end rounded and one flat. No. 1, B.	30½	78	78	3 12			6278	6278	
Both ends flat. No. 1, C.	30½	78	78				9625	9007	
Both ends flat. No. 1, C.	30½	78		.....	.....	.....	8389		
Both ends rounded. No. 1, A.	30½	100	100	6 2			7397	7009	
Both ends rounded. No. 1, A.	30½	101		6 2½	.....	.....	7769		
Both ends rounded. No. 1, A.	30½	101		6 4½	.....	.....	7672		
Both ends rounded. No. 1, A.	30½	99		.....	.....	.....	6105		
Both ends rounded. No. 1, A.	30½	99		.....	.....	.....	6105		
One end rounded and one flat. No. 1, B.	30½	102	100	6 4			14685	13499	
One end rounded and one flat. No. 1, B.	30½	98		5 14	.....	.....	12314		
One end rounded and the other flat with a disc of double the diameter. No. 2, B.	30½	100	100	6 7	-09	12445		13565	{ Broke 10-42 inches from the rounded end, after bearing the weight some minutes.
						1300	12893		
						2-95	13789		
						-13	12445		
One end rounded and the other flat with a disc of double the diameter. No. 2, B.	30½	100			-20	12893	13341		{ Broke 10-30 inches from rounded end.
Both ends flat. No. 1, C.	30½	101	101				19132	20310	
Both ends flat. No. 1, C.	30½	102		.....	.....	.....	21844		
Both ends flat. No. 1, C.	30½	100		.....	.....	.....	18369		
Both ends flat. No. 1, C.	30½	100		.....	.....	.....	21897		
Both ends flat with discs. No. 2, C.	30½	100		6 15	-05	12445	.....		
			100		-06	14685		22475	
					-07	16925	.....		
					-09	18045	.....		
					-15	20285	.....		
					-27	21629	21853		
					-02	14685	.....		
					-04	16925	.....		
Both ends flat with discs. No. 2, C.	30½	100			-06	19165			
					-09	21405			
					-15	22525	23097		
Both ends rounded. No. 1, A.	60½	176	176	38 0			16493	16493	
One end rounded and one flat. No. 1, B.	60½	174	174	37 0			33557	33557	

TABLE VI.—Pillars enlarged in the middle: ends rounded.

Experiments to ascertain the Resistance of Pillars of Cast Iron, the Low Moor, No. 3, formed in the shape of frustums of double cones, the bases meeting in the middle, and the extreme ends left prominent in the centre, that the force might pass through the axis. Length of pillar $60\frac{1}{2}$ inches. Plate XV. No. 4, A, B, C, D.

End diameter.	Middle diameter.	Weight of column.		Breaking weight.	Mean breaking weight.	Strength, or breaking weight of a uniform cylindrical pillar of the same weight as the mean.	Gain in parts of mean breaking weight.	Remarks.
inch.	inch.	lbs.	oz.	lbs.	lbs.	lbs.		
1-01	1-27	16	5	4521	4521	3838	$\frac{1}{875}$	{ This pillar broke five inches from the middle, where the diameter was 1-24.
1-05	1-56	20	12	6453	7085	6205	$\frac{1}{870}$	The last of these broke ten inches from the middle, where the diameter was 1-43; and also $11\frac{1}{2}$ inches from the middle at the other end.
1-05	1-55	21	0	7573				
1-03	1-56	21	6	7229				
		21 lbs. 1 oz.						
1-04	1-85	26	8	11069	11069	9555	$\frac{1}{791}$	{ This broke fifteen inches from the middle and toward the other end.
1-05	1-82	.....	.....	10985	10985	.....	.....	{ This broke 164 inches from the end, at a flaw, it is therefore not used for comparison.
1-00	1-97	28	0	12245	12245	$\left\{ \begin{array}{l} 10597 \\ 10344 \end{array} \right\}$	$\frac{1}{870}$	{ This broke 20-35 inches from the middle, where the depth of the tensile part was to that of the compressed as 105 : 27.
						Mean 10470.		

The strengths of the uniform pillars, of equal weight with those of variable thickness, in the Table above, were calculated from the experiments upon the pillars whose mean weights are 19 lbs. 11 oz., and 28 lbs. 7 oz., in Table I.: it having been shown (Art. 46.) that the strength, where the length is the same, varies as the 1-88 power of the weight, in pillars with rounded ends.

TABLE VII.—Pillars enlarged in the middle, differing from the last only in having discs upon the ends, two inches diameter, and half an inch thick, turned flat. Length $60\frac{1}{2}$ inches. Plate XV. No. 4, E, F.

End diameter.	Middle diameter.	Weight of pillar.		Mean weight of pillar.	Deflection.	Corresponding weight.	Breaking weight.	Mean breaking weight.	Breaking weight of uniform pillars of same weight, with discs.	Remarks.
inch.	inch.	lbs.	oz.	lbs.	inch.	lbs.	lbs.	lbs.	lbs.	
1-04	1-31	16	10		-03	4251				The first of these pillars, with enlarged middle, broke $9\frac{1}{4}$ inches from the middle, and had both discs split. A wedge breaking out, at the place of fracture, showed the depth of tension to that of compression as 104 : 16. The next pillar gave the ratio 104 : 22, breaking $7\frac{1}{2}$ inches from the middle, as well as one end breaking off, and the disc at the other splitting.
					-05	8171				
					-09	8955				
					-12	9739				
					-17	10525				
					-28	11307	12091			
1-00	1-27	16	4 16	10			10915	11526	11756	The third pillar broke 11-6 inches from the middle, and had both discs split. The pillar, with enlarged middle, bore $\frac{1}{16}$ th less than the uniform pillar.
1-03	1-27	17	1				11573			
1-06	1-56	21	13 21	13	-06	13699				This pillar, with enlarged middle, broke $7\frac{1}{2}$ inches from middle; it bore $\frac{1}{16}$ th part more than the uniform one.
					-07	14459				
					-12	15803				
					-16	17147				
					-29	18491				
					-50	18939	19163	19163	16924	

The strengths of the uniform disced pillars, of the same weight and length as those with enlarged middles, were calculated according to the assumption that the strength varied as the 1.775 power of the weight. See Art. 46.

The first was obtained from a mean between the results of two experiments, where an uniform disced pillar of the same length, and 15 lbs. 14 oz. weight, was broken with 10831 lbs.; and the second, from a like mean, in which a disced pillar of that length, and 21 lbs. 6 $\frac{1}{2}$ oz. weight was broken with 16369 lbs.

TABLE VIII. (Continued.)

No. of Experiment.	Description of Pillar.	Deflection.	Weight producing the deflection.	Breaking weight, or that with which it sunk.	Value of s from formula $s = \frac{W}{12 \pi^2 E I}$ where W = the breaking weight, and I , s the external and internal diameters.	Remarks.
7.	Hollow uniform cylinder. External diameter 2.24 Internal diam. by measure 1.58	inches. -01? -02 -05 -09 -17 -21	lbs. 2141 4325 6341 11169 13129 13521	lbs. 13913	lbs. 917.62	After bearing 6341 lbs. the pillar was unloaded and returned to .00 deflection. This pillar was reduced to half its thickness near to the ends, and to three-fourths half way between the middle and each end; but it did not fail through this, and sunk by flexure, the curvature being greatest in the middle, as in other cases.
8.	Hollow uniform cylinder. External diameter 2.49 Internal diam. by measure 1.89 Internal diameter by calculation 1.89 Mean... 1.89 Weight of pillar 48½ lbs.	bent. -01? -02 -04 -00 -19 -40 -52	lbs. 3355 4123 6139 10171 16115 18623 19230	lbs. 19855	lbs. 996.24	This pillar was reduced in the same way as the last. When broken, which took place eight inches from the middle and not at the reduced parts, it showed that the ver sin, or depth of tension, was to that of compression as 19 : 6 nearly. The casting was very good, and the core in the middle.
9.	Hollow uniform cylinder. External diameter 2.47 Internal diam. by measure 1.99 Internal diameter by calculation 1.97 Mean... 1.98 Weight of pillar 41 lbs.	-01? -02 -23 -32 -62	lbs. 2911 8553 17391 18029 18667	lbs. 19003	lbs. 1123.5	Variation of thickness of metal at place of fracture 7 : 9.
10.	Hollow uniform cylinder. External diameter 2.46 Internal diameter by measure 1.87 Internal diameter by calculation 1.84 Mean... 1.855 Weight of pillar 49 lbs.	bent. -01? -02 direction altered. -04 -09 -14 -28 -40 -49 -65	lbs. 2141 4381 7341 9103 12445 14359 16487 17551 18083 18615	lbs. 19147	lbs. 989.95	It broke at a part rather unsound, 13½ inches from the middle. The thicknesses of the metal on opposite sides, at the place of fracture, were as 3 : 4.
11.	Hollow uniform cylinder. External diameter 2.73 Internal diam. by measure 2.14 Internal diameter by calculation 2.20 Mean... 2.17 Weight of pillar 48 lbs.	bent. -01? direction altered. -05 -05 -40 -70	lbs. 3603 8185 12105 16025 21219 22787	lbs. 23963	lbs. 949.48	When broken, the cylinder was somewhat thinner on one side than the other, and the thin side was that which was compressed; as was the case in most of the instances where the cylinders were not equal in thickness at both ends.
12.	Hollow uniform cylinder. External diameter 2.74 Internal diameter by measure 2.14 Internal diameter by calculation 2.17 Mean... 2.155 Weight of pillar 51½ lbs.	-02 -05 -07 -08 -14 -37 -62 -1.10	lbs. 3603 8186 12105 16025 21219 25139 26707 27491	lbs. 27883	lbs. 1059.5	This broke three inches from the middle, and a crack showing the neutral line gave the ver sin of the part submitted to tension = 1.76 inches. Variation of thickness of metal at place of fracture 2 : 3 nearly.
13.	Hollow uniform cylinder. External diameter 3.01 Internal diam. by measure 2.45 Internal diameter by calculation 2.51 Mean... 2.48 Weight of pillar 50½ lbs.	-07 -14 -23 -30 -44 -75	lbs. 16115 18667 21219 22787 24355 25923	lbs. 26707	lbs. 819.46	This casting was allowed to break, and the thicknesses of the metal at opposite sides of the place of fracture were as 9 : 15. The thin side was the compressed one. The depth or ver sin of compression was to that of extension as 1 : 5.

TABLE VIII. (Continued.)

No. of Experiment.	Description of Pillar.	Deflection.	Weight Producing the deflection.	Breaking weight, or that with which it sunk.	Value of s from formula $s = \frac{W}{D^3 - d^3}$ where W = the breaking weight, and D, d the external and internal diameter.		Remarks.
					lbs.	lbs.	
14.	inches.	inch.	lb.	lb.			The thicknesses of the metal, on opposite sides, at the place of fracture, were as 19:34; the thinner side being the compressed one.
	Hollow uniform cylinder.		16115				
	External diameter 3.36	.09	18667				
	Internal diameter by measure 2.81	.13	21219				
	Internal diameter by calculation 2.836	.19	33571				
		.23	35923				
		.27	38275				
		.32	30627				
	Mean... 2.823	.41	32979				
	Weight of pillar, 7 ft. 6½ inches long, 59½ lbs.	.50	35531				
		.61	36507				
		.69	37783				
		.81	39057				
		1.10	40335	40973	885.02		
15.	Hollow uniform cylinder.	bent.	3355				The thickness of the metal varied as 30:43, or 5:7 nearly, the thinner side being compressed.
	External diameter 3.36	.09	16115				
	Internal diameter by measure 2.61	.13	18667				
	Internal diameter by calculation 2.65	.15	21729				
		.17	24148				
		.24	28986				
		.30	33824				
	Mean... 2.63	.38	37701				
	Weight of pillar, 7 ft. 6½ inches long, 77½ lbs.	.48	41632				
		.59	43597				
		.67	45563				
		.87	47528				
		.90	48511				
		1.07	49494	50477	880.11		
16.	Solid uniform pillar cast in green sand.	bent.	2141				This experiment, on a solid cylindrical pillar, is given for comparison with the others, which were all on hollow ones.
	Diameter 2.24 inch.	.0057	5161				
	Weight 93 lbs.	.02	7541				
	It was rounded at the ends.	.06	unloaded.				
		.05	15737				
		.12	18761				
		.25	20273	21281	1026.6		
17.	Hollow uniform cylinder.						In this casting the metal was nearly of equal thickness all round. The value of s or 927.86, is reduced by calculation to that of a pillar 7 ft. 6½ inches long, according to the ratio obtained in the preceding part of this paper, where it was found that the strength varied inversely as the 1.7 power of the length. This remark will apply to the following pillars. This casting was not very sound.
	External diameter 1.78 inch. Internal diameter 1.21 inch. Length 4 ft. 9 inches.			13693	927.86		
18.	Hollow uniform cylinder.						This casting was sound, and the thicknesses of the metal on opposite sides were as 10:21.
	External diameter 2.31 inch. Internal diameter 1.67 inch. Length 4 ft. 9 inches.			36382	1005.3		
19.	Hollow uniform cylinder.	.35	32587	33763	784.9		The thicknesses of the metal on opposite sides were as 11:15. In this pillar the length was 16½ times the diameter, and the fracture took place by flexure as before; but a wedge was formed near the centre, which split the pillar at the place of fracture, and seemed to be an axis round which it turned.
	External diameter 1.85						
	Internal diameter by measure 1.35						
	Internal diameter by calculation 1.37						
	Mean... 1.36						
Length 2 ft. 7 inches. Weight of 2 ft. 5 inches = 8 lbs. 15½ ozs.							

TABLE IX.—Hollow Cylinders flat at the Ends.

Results of Experiments on the Strength of Hollow Cylinders of Cast Iron (Low Moor, No. 3.), the ends being turned flat and perpendicular to the sides, and the pressure communicated by the approach of parallel surfaces, against which the ends of the pillar were firmly bedded. Length of each pillar 7 feet 6½ inches, except otherwise mentioned. Plate XV. No. 8, A, B, C, and D.

No. of Experiment.	Description of Pillar.	Deflection	Weight Producing the deflection.	Breaking weight, or that with which it sunk.	Value of s from formula $s = \frac{W}{D^3 - d^3}$ where W = the breaking weight, D , d the external and internal diameters; and the length of the cylinder = 7 feet 6½ inches.		Ratio of the thickness of the ring of metal on opposite sides at place of fracture.	Remarks.
					s	s		
1.	Hollow uniform cylinder, same as in Experiment 1. of the preceding table.	inch.	lbs.	lbs.				When this cylinder was broken, it was found that the thinner side was that which was compressed. This cylinder was not reduced in its thickness toward the ends. The weight of all the cylinders below, whether their lengths are 7 feet 6½ inches, or 7 feet 4½ inches, are given for the greater length.
		·02	3813					
		·03	3821					
		·06	4830	unloaded				
		inch.						
		External diameter	·78	5837				
		Internal diameter by measure	·121	6845				
		Internal diameter by calculation	·11	8861				
		Internal diameter by calculation	·17	10677				
		Internal diameter by calculation	·21	13901				
		Mean... 1·21	·30	14353				
		Length of cylinder 7 ft. 4½ inches.	·42	15091				
		Weight (length 7 ft. 6½ in.) 31 lbs.	·50	16705	17840	2973·7	1:5	
			·66	17489				
2.	Hollow uniform cylinder, same as in No. 2. preceding table.							This cylinder was reduced to half its thickness near to the ends, and to three-fourths of its thickness half way between the middle and the ends; but the weight of the cylinder as set down is for the whole before it was reduced. The fracture took place in the middle, and in another place near to it, but not in the reduced parts.
		·12	11917					
		·17	13177					
		External diameter	·32	15137				
		Internal diameter	·187	15091				
		Length of cylinder 7 ft. 4½ inches = 304 lbs.	direction changed. ·54	16313	16705	3081·5	7:11	
3.	Hollow uniform cylinder.		bent	2141				This cylinder was reduced in the same manner as the last, or somewhat more, and the fracture took place at the reduced part, half way between the middle and one end; where the external diameter was 1·60 and the internal 1·18, and the thickness of the metal on the opposite sides = ·09 + ·32 = ·41. But the thickness of the metal in the middle of the pillar was 1·76 - 1·18 = ·58; therefore the reduced part was somewhat less than three quarters of the whole.
		External diameter	·76	2749				
		Internal diameter by measure	·118	5437				
		Internal diameter by measure	·06	6333				
		Internal diameter by measure	·09	6677				
		Internal diameter by measure	·25	13721				
		Internal diameter by measure	·36	15233				
		Internal diameter by calculation	·54	16241	16745	2968·7	1:3	
		Mean... 1·11						
		Weight of cylinder 32 lbs.						
4.	Hollow uniform cylinder.		·01	2237				This pillar was a good sound casting, and was not reduced in its thickness in the manner of the last two.
		External diameter	·75	4441				
		Internal diameter by measure	·109	6569				
		Internal diameter by measure	·10	8165				
		Internal diameter by measure	·12	13445				
		Internal diameter by calculation	·14	13789				
		Internal diameter by calculation	·15	15133				
		Mean... 1·11	·19	16477				
		Weight of cylinder 32 lbs.	·25	17891				
			·31	18493				
			·36	19165				
			·42	19613				
			·46	20061	20857	3586·9	1:2	
			·55	20509				

TABLE IX. (Continued.)

No. of Experiment.	Description of Pillar.	Deflection.	Weight producing the deflection.	Breaking weight, or that with which it sunk.	Value of s from formulae $s = \frac{W}{D^2 - d^2}$ where W = the breaking weight, D , d the external and internal diameter; and the length of the cylinder = 7 feet 6½ inches.		Ratio of the thickness of the ring of metal on opposite sides at place of fracture.	Remarks.
					lbs.	lbs.		
5.	Hollow uniform cylinder.	inches.	lbs.	lbs.				This column was not reduced in thickness as above; it was a good casting, of equal thickness on all sides. A wedge broke out at the place of fracture which was 4½ inches from the middle, and showed that the vein, or depth of the part in a state of tension, was 1·72 inch; ∴ depth of compressed part = 2·04 - 1·72 = 32 inch. See W. (Plate XV., No. 8, D).
	External diameter	2·04	3380					
	Internal diameter by measure	1·44	11091					
	Internal diameter by calculation	1·49	14703					
	Mean... 1·46		17391					
	Length of cylinder 7 ft. 4½ inches.		29011					
	Weight of cylinder 7 ft. 6½ inches = 35½ lbs.		23481					
			25105					
			26739					
			28353					
			29977					
			31601	32413	3573·8	1 : 1		
6.	Hollow uniform cylinder.							This cylinder had a slight bubble in the place of fracture, which it was conceived had little influence on the strength. The ends of the cylinder were not reduced.
	External diameter	2·01	3589					
	Internal diameter by measure	1·336	5819					
	Internal diameter by calculation	1·407	12691					
	Mean... 1·368		18667					
	Length of cylinders 7 ft. 6½ ins.		21857					
	Weight of cylinder 37½ lbs.		25105					
			26739					
			28353					
			29977	30789	3390·3	7 : 10		
7.	Hollow uniform cylinder, same as No. 3. of Table VIII.	bent	4251					This cylinder was the same as that in Experiment 3. of the last Table. It was rendered quite straight, and its ends were firmly bedded against the crushing surfaces. Previous to this experiment, however, the cylinder was reduced to half the thickness near to the ends, and to three quarters of the thickness half way between the middle and the ends. In the former cases, where the cylinder was reduced, the fracture took place only in the middle, but in this, the pillar broke both in the middle and at the two reduced places half way between the middle and the ends. It was broken too at the reduced part near to one end, and the other end was split. Casting moderately sound; the thicker side of the casting was the compressed one in this instance.
	External diameter	bent	5819					
	Internal diameter by measure	1·40	21857					
	Internal diameter by calculation	1·43	25917					
	Mean... 1·415		27541	28353	3214·8	5 : 11		
	Length of cylinder 7 ft. 4½ inches.							
	Weight of cylinder 7 ft. 6½ inches = 36½ lbs.							
8.	Hollow uniform cylinder.	bent	1456					This cylinder was reduced in the manner of the preceding ones. It bent upwards of an inch, and then broke; first at a small flaw near the middle, then at the reduced part half way between the middle and one end. A piece broke off at the neutral line; it was nearly straight across in a line with the inner diameter. Depth of compression = 36 inch.
	External diameter	1·99	3355					
	Internal, both by measure and calculation	1·31	15605					
	Length of cylinder 7 ft. 5·8 ins.		17755					
	Weight of cylinder 7 ft. 6½ inches, before reduction 39 lbs.		18605					
			229055					
			24205					
			26731	27067	2988·3	6 : 7		

TABLE IX. (Continued.)

No. of Experiment.	Description of Pillar.	Deflection.	Weight producing the deflection.	Breaking weight, or that with which it sunk.	Value of s from formula	Ratio of the thicknesses of the ring of metal on opposite sides at place of fracture.	Remarks.
					$s = \frac{W}{D^2 - d^2}$ where W = the breaking weight, D , d the external and internal diameters; and the length of the cylinder = 7 feet 6 1/2 inches.		
9.	Hollow uniform cylinder, same as No. 5. last table.	inch.	lbs.	lbs.	lbs.	4:9	This cylinder was reduced in thickness in the same manner, and to the same degree, as before. It broke in six pieces, in the middle, at one of the reduced parts half way between the middle and the ends, where the diameter was 2.12 inches, and had both of its ends split. In this, and the preceding cases, the fracture seems to have taken place, first in the middle, and afterwards, by reaction, in the other places; but it is possible that some cracking at the ends preceded the rupture.
	inches. External diameter 2.23 Internal diameter by measure 1.53 Internal diameter by calculation 1.55 Mean.... 1.54 Length of cylinder 7 ft. 4 1/2 inches. Weight of cylinder 7 ft. 6 1/2 inches, before reduction 47 lbs.			406.69	3069.0		
10.	Uniform solid cylinder cast in green (moist) sand. Diameter 1.76 inch. Length 7 feet 6 1/2 inches. Weight 56 lbs.	bent	4135				With 23179 lbs. it became bent more than an inch, and slipped out of the place; it was afterwards rendered straight and replaced; and it would have broken with a less weight.
		bent	10855				
		.35	21219	23179	3115.5		
		.65	22787				
11.	Uniform solid cylinder cast in dry sand. Diameter 1.72 inch. Length 7 feet 6 1/2 inches. Weight 53 lbs 8 oz.	.20	16115				With the last weight, 21995, the pillar slipped from its fixings, as the preceding one had done, and when replaced it was broken with a less weight than it had borne before. The weight, in both this case and the last, was so near to what the breaking weight must have been, if the fracture had been effected as usual, that I have not hesitated to put down the results as those of fracture.
		.23	17335				
		.28	18355				
		.35	19475				
		.44	20595				
		.65	21715	21995	3207.7		

TABLE X.—Uniform Hollow Cylindrical Pillars of Low Moor Iron, No. 3; the ends being flat, and the lengths less than thirty times the external diameter. Plate XV. No. 8, E, F.

Number of Ex- periment.	Length of pillar.		External diameter.		Internal diameter.		Weight of pillar.		Breaking weight.	Value of b .	Value of c .	Calculated breaking weight from formula. $\frac{bc}{b + \frac{1}{4}c}$.	Remarks.
	inches.	feet.	inch.	inch.	inch.	inch.	lbs. oz.	lbs.					
1.	30.25	= 2.5208	1.26	.767	6	2	33679	38807.6	86179.5	32331			Not perfectly sound.
2.	30.25	= 2.5208	1.26	.781	6	1	32867	38274	84310	31790			{ Core not quite in middle, thicknesses of metal on opposite sides 3 : 4.
3.	.26	= 2.1666	1.25	.765	5	2	35302	48461.7	83882	36501			Air bubbles in casting.
4.	.26	= 2.1666	1.17	.752	4	7	31185	36887	69283.2	28764			Core in centre, T : C : 43 : 74.
5.	.23	= 1.9166	1.16	.7705	3	9	30383	43833	64844.7	30291			Core in centre, T : C : 11 : 18.
6.	30.166	= 1.6805	1.21	.77	3	9	41751	64599.2	75130.6	40128			{ Core in centre, broke in middle in many pieces with sharp points.
7.	30.166	= 1.6805	1.14	.605	2	11	27135	46408	56193	29449			Broke in middle in twelve pieces.
8.	.17	= 1.4166	1.15	.91	1	11	35511	50927	49636	26191			
9.	.16	= 1.3333	1.15	.99	1	9	25105	54730	41053	26273			Broke in middle in twenty-five pieces.
10.	15.125	= 1.2604	1.16	.932	1	8	26729	61304.1	41133.8	27364			Core in centre, T : C : 52 : 64.
11.	15.125	= 1.2604	1.08	.77	1	12	27135	61579.2	49457	30863			
12.	.14	= 1.1666	1.15	.792	3	0	37285	91908	59953	40257			
13.	.8	= .7333	1.12	.91	13	34437	133000	38704	31750				Broke in middle in ten pieces.

Most of the pillars, which were under twenty inches long, were turned outside and bored within. The whole in this table were (with the exceptions named) very good, and the core was nearly in the centre of all, except the 2nd. By the ratio T : C is to be understood the depth of the part extended to that compressed in the section of fracture.

By the values of b in the seventh column is to be understood the breaking weights calculated from the formula $b = 99318 \frac{D^{3.55} - d^{3.55}}{l^{1.7}}$, for long pillars (Art. 51.); where l is the length of the pillar, and D, d the external and internal diameters. The values of c in the eighth column are the weight which would crush, without flexure, a mass of iron of the same section as the pillar (Art. 55); and the breaking weight in the ninth column is computed by the formula (Art. 43.) for short pillars: strength $= \frac{bc}{b + \frac{1}{4}c}$. It having been shown, I hope satisfactorily, that the strength of short pillars, which break by flexure, depends upon their resistance to crushing (Art. 39–42.), I have endeavoured there to show the laws on which it depends; and the agreement between the calculated and the experimental results, in hollow pillars, may be judged of from the above results.

TABLE XI.—Pillars of various forms and different modes of placing.

No. of Experiment.	Description of pillar (all being cast from the same iron as before).	Deflection.		Weight producing the deflection.	Breaking weight.	Remarks.
		inch.	lbs.			
1.	Round hollow pillar, regularly tapering from the middle to the ends, like the frustums of two cones, whose bases joined in the middle of the pillar. Plate XV. No. 9, C, where the external diameter was 2.24 inches, and the internal 1.63 inch. The extreme diameter near the end was 1.73 inch; the length of the pillar 7 ft. 6½ inches, its weight 56 lbs. It had strong discs at the ends, 2½ inches diameter, turned flat; but was cast to be everywhere else of uniform thickness.	.04 .07 .17 .18 .34 .54	4135 10855 21219 after hanging one hour. 25139 27099		98667	It broke in five parts; 2½ and 11 inches from the middle, and near the disc at each end; the fracture seeming to have taken place first near the middle. The thickness of the metal at the place nearest to the middle was .33 + .25 = .58 inch; and at the other near to it .33 + .26 = .59 inch. At this last place a wedge broke out, which showed the compressed part to be $\frac{1}{16}$ th of the diameter.
2.	Round hollow pillar from the same model as the last. External diameter in middle 2.24 inches. External diameter near to the ends 1.73 inch. Length of pillar 7 ft. 6½ inches. Weight of pillar 56½ lbs. Plate XV. No. 9, D.	bent. .03 .15 .35 .65	3803 12105 21219 25139 27099		97491	It broke eighteen inches, and twenty-five inches, from the middle at the same end, and at the disc at that end. A wedge broke out which showed the compressed part to be $\frac{1}{16}$ th of the diameter. The thickness of the metal at the place of fracture nearest to the middle was .19 + .34 = .53 inch; and in another place .34 + .25 = .59.
3.	Round hollow pillar, regularly tapering from the bottom to the top; as the frustum of a hollow cone. Plate XV. No. 9, A or B. External diameter at bottom 2.22 inches. External diameter at top 1.70 inch. Internal diameter at bottom 1.61 inch. Length of pillar 7 ft. 6½ inches. Weight of pillar 39 lbs. Its ends were turned flat, and it had a strong disc upon the top of double the diameter there, all the rest was cast to be of uniform thickness.	bent. .02 .12 .22 .30 .42 .60 .87	3355 12403 21857 25917 28553 29977 31801 32413		89413	It broke about two inches below the middle, with the last weight, after bearing it about a minute. Thickness of metal there .25 + .36 = .61 inch. The disc at the top of this pillar was intended to give it a firmer bedding than it could otherwise have had from its small diameter.
4.	Round hollow pillar of the same form as the last, but from a different model. External diameter at bottom 2.32 inches. External diameter near top 1.75 inch. Diameter of disc at top of pillar 3 inches, its thickness being 9 inch. Length of pillar 7 ft. 6½ inches. Weight of pillar 34 lbs. 9 ozs. The pillar, excepting the disc, was cast to be everywhere $\frac{1}{4}$ inch thick. Plate XV. No. 9, A or B.	.06 .09 .20 direction altered a little. .28 .45 .62 .80	6617 12105 17596 20739 22027 24045 25387		90563	The fracture took place 2 ft. 11½ inches from the bottom, where the external diameter was 2.08 inches, and the internal 1.57 inch. The thickness of metal on the opposite sides there was .35 + .15 = .50 inch. The thin side was, as often happened, the compressed one; and a small wedge broke out at the place of fracture, showing that two-thirds of the diameter at least was in a state of tension. There was a defect called "cold shot" about one-eighth of an inch in diameter in the tensile part of the fracture, which would reduce the strength a little.
5.	Uniform pillar, whose section was of the form in Plate XV. No. 6, B, where $a = b = c = d = 3$ inches, and the thickness of the ribs = .48 inch. Length of pillar 7 ft. 6½ inches. Weight of pillar 62 lbs. The ends were rounded, that the force might pass through the axis.	.04 .07 .14 .25 .45	11169 13129 15089 16100 17175		17578	It sunk down, bending in the direction of one of the ribs. This experiment was made to give some idea of the strength of a connecting rod of the usual form, as compared with that of a hollow cylinder of the same weight and length.
6.	Uniform pillars, whose section was cast to be equal in area to that in experiment 5, but of the form in Plate XV. No. 6, A, in which $a = b = c = d = 3$ inches, $e = f = 2\frac{1}{2}$ inches. Length of pillar 7 ft. 6½ inches. Weight of pillar 63½ lbs. Ends rounded.	.07 .13 .25	19863 22868 25507		20571	It broke by bending in the direction a, b, c, and was but little bent in the direction e, f.
7.	Solid uniform cylinder, formed at the ends so that the strain would not pass through the axis, but in a line half way between the centre and the circumference. Diameter of pillar 1.95 inch. Length of pillar 60.5 inches. Weight of pillar 45 lbs. 14 ozs. Plate XV. No. 5, B.	.96* 1.30	11011 12691		13195	*The deflections here given are not those from the whole length of the pillar, as in all other cases, but from a length of 4 ft. 8½ inches of the middle of it.

TABLE XI. (Continued.)

No. of Experiment.	Description of pillar (all being cast from the same iron as before).	Deflection.	Weight producing the deflection.	Breaking weight.	Remarks.
8.	Solid uniform cylinder, differing from the last only in the ends being formed so that the strain passed in a line further from the centre, or $\frac{1}{4}$ th of the diameter from one side. Diameter of cylinder 1.96 inch. Length of pillar 60.5 inches. Weight of pillar 46 lbs. 5 ozs.	inch.	lbs.	14697	The deflections of this pillar were for a length 4 ft. 8 $\frac{1}{2}$ inches, as in the last case.
		.36	7341		
		.47	8685		
		.54	9893		
		.79	11169		
		.92	11953		
9.	Solid uniform cylinder fixed so that the pressure passed diagonally through the opposite corners. Diameter of pillar .97 inch. Length of pillar 30.25 inches. Weight of pillar 5 lbs. 13 ozs. Plate XV. No. 5, A.	1.15	12737	5750	
		1.38	13521		
		1.48	14305		
10.	Cylinder, same as the last and broke in the same manner. Length of pillar 30 $\frac{1}{2}$ inches. Diameter of pillar 1.02 inch. Weight of pillar 6 4 $\frac{1}{2}$ ozs.			7275	Taking a mean from these two experiments, we have a cylinder, diameter .995 inch, length 30 $\frac{1}{2}$ inches, weighing 6 lbs. $\frac{1}{2}$ oz., broke with 6512 lbs.

TABLE XII.—Experiments on the Resistance of Pillars of the best Staffordshire Wrought Iron and Steel.

Description of Pillar.	Length of pillar.	Diameter of pillar.	Mean diameter of pillar.	Weight of pillar.	Mean weight of pillar.	Deflection.	Weight causing the deflection.	Breaking weight.	Mean breaking weight.	Remarks.
1st. WROUGHT IRON.	ft. ins.	inch.	inch.	lbs. oz.	lbs. oz.	inch.	lbs.	lbs.	lbs.	
Solid uniform cylinder, both ends rounded Plate XV. No. 1, A.	7 6½	1-02	1-017	20 4½	20 3½	bent.	296	1825	1808	The results here given are the means from two experiments. The ends of the pillar were not perceptibly flattened by the pressure.
						-03	352			
						-04	800			
						-05	1360			
						-12	1640			
Solid uniform cylinder, both ends rounded...	7 6½	1-015		20 2		-42	1790			
						bent.	240			
						-03	352			
						-04	800			
						-11	1360			
						-48	1790	1792		
Solid uniform cylinder, both ends rounded...	5 0½	1-015	1-015	13 0	12 15½	-07	2804	3812	3938	The ends of the pillars were little or none crushed, or flattened by the pressure.
Solid uniform cylinder, both ends rounded...	5 0½	1-015		12 15½		-10	3308	4064		
Solid uniform cylinder, both ends rounded...	2 6½	1-015	1-015	6 12	6 12	-0	2237	14869	15480	In this pillar and the next the ends were rendered flat by the pressure; the diameter of the flattened part in each was ¼ inch.
						-01	4537			
						-02	8121			
						-05	12181			
						-06	12335			
Solid uniform cylinder, both ends rounded...	2 6½	1-015		6 12		-06	14869	16213		
Solid uniform cylinder, both ends rounded...	2 6½	1-015		6 12				15357		This pillar had the ends tipped with hardened steel to prevent it being crushed.
Solid uniform cylinder, both ends rounded...	2 6½	-52	-52	1 13	1 13	-0?	742	1330	1260	Ends little or none crushed.
						-05	1246			
Solid uniform cylinder, both ends rounded...	2 6½	-52		1 13		-17	1078	1162		
Solid uniform cylinder, both ends rounded...	2 6½	-52		1 13		-10	1078	1246		
						-24	1246	1288		
Solid uniform cylinder, both ends rounded...	1 8½	1-015	1-015					23312	20834	The ends of this cylinder were somewhat crushed and flattened. This cylinder had its ends tipped with hardened steel to prevent them becoming flattened.
Solid uniform cylinder, both ends rounded...	1 8½	1-015						18356		
Solid uniform cylinder, both ends rounded...	1 3½	1-005	1-005	3 5½	3 5½			23395	23535	Ends rendered flat by the pressure to ¼ the diameter, or ¼ the area. The ends of this were tipped with steel, but as it was not hardened, the ends became flattened, though in a less degree than in the last instance.
Solid uniform cylinder, both ends rounded...	1 3½	1-005		3 5½				23675		
Solid uniform cylinder, rounded at one end and flat at the other. Plate XV. No. 1, B.	7 6½	1-02	1-02	20 5	20 5	bent.	1080	3355	3355	In this pillar the greatest flexure was about 2 feet 11½ inches from the rounded end.
						-02	1920			
						-07	2480			
						-15	3040			
						-27	3320			
Solid uniform cylinder, rounded at one end and flat at the other.	5 0½	1-03	1-03	13 12				8137	8137	The rounded end was much flattened by the pressure in the shorter pillar, and slightly so in the longer, which had left a flat part at the end 28 inch diameter.
Solid uniform cylinder, rounded at one end and flat at the other.	2 6½	1-015	1-015	6 13	6 13			21355	21355	

TABLE XII. (Continued.)

Description of Pillar.	Length of pillar.	Diameter of pillar.	Mean diameter of pillar.	Weight of pillar.	Mean weight of pillar.	Deflection.	Weight causing the deflection.	Breaking weight.	Mean breaking weight.	Remarks.
	ft. ins.	inch.	inch.	lbs. oz.	lbs. oz.	inch.	lbs.	lbs.	lbs.	
1st. WROUGHT IRON. Solid uniform cylinder, one end rounded and a disc on the other. Plate XV. No. 2, B.	2 6½	1-015	1-015	7 2				22699	21187	{ Rounded and flattened by the pressure. The rounded end of this was tip with hardened steel to prevent crushing. The greatest deflection was about 1½ inches from the rounded end.
Solid uniform cylinder, one end rounded and a disc on the other.	2 6½	1-015						19675		
Solid uniform cylinder, rounded at one end and flat at the other. Plate XV. No. 1, B.	1 3½	1-005	1-005	3 5½	3 5½			28075	26227	{ It became crushed at the rounded end, so that the flattened part was .55 inch diameter. The greatest deflection was about 7 inches from rounded end, or ¼ inch from middle. This had the rounded end tip with hardened steel.
Solid uniform cylinder, rounded at one end and flat at the other.	1 3½	1-005						24379		
Solid uniform cylinder, flat at both ends ... Plate XV. No. 1, C.	7 6½	1-02	1-02	20 6	20 6	.40 .07 .11 .14 .15 .19 .22 .28 .37 .43	324 800 1360 1920 2480 3040 3600 4160 4730 5000	5280	5280	
Solid uniform cylinder, flat at both ends ...	5 0½	1-02	1-02	13 11	13 11			12990	12990	
Solid uniform cylinder, flat at both ends ...	2 6½	1-015	1-015	7 1½	7 1½	.05	22027	23371	23371	
Solid uniform cylinder, with disc at both ends. Plate XV. No. 2, C.	2 6½	1-015	1-015	7 10½	7 10½	.40 .04	22027 25387	25387	25387	{ It sunk with this weight after bearing it some minutes.
Solid uniform cylinder, flat at both ends. Plate XV. No. 1, C.	1 3½	1-005	1-005	3 7½	3 7½			27099	27099	
Solid uniform cylinder, flat at both ends ...	1 3½	1-005						27099		
2nd. CAST STEEL. NOT HARDENED.										
Solid uniform cylinder, rounded at both ends. Plate XV. No. 1, A.	29-95	.87		5 2½				10516	10516	{ It bore this weight some minutes, and then sunk gradually by bending; ends slightly flattened by pressure.
Solid uniform cylinder, one end rounded and the other flat. Plate XV. No. 1, B.	29-95	.87		5 3				20315	20315	{ Flattened a little at the rounded end; greatest curvature between ¾ and ¼ of the length from the rounded end.
Solid uniform cylinder, both ends flat. Plate XV. No. 1, C.	29-95	.87		5 3½		.07 .10 .11	18667 22027 25387	26059	26059	{ It bore this five minutes, and then sunk; the ends were not split, as frequently happened, in a slight degree, both in cast and wrought iron.

Dantzic Oak.

TABLE XIII.—Square Pillars of Dantzic Oak, from a very good plank, which had been cut up about nine months.

Description of Pillar.	Length of pillar.	Side of square.	Weight of pillar.	Deflection.	Corresponding weight.	Breaking weight.	Mean breaking weight.	Remarks.									
	inches.	inches.	lbs. oz.	inches.	lbs.	lbs.	lbs.										
Uniform pillar rounded at the ends } that the force might pass through } the axis. Plate XV. No. 3, A. ... }	60.5	1.75		.09 .17	3237 3197	3645	3197	Broke anglewise; it was slightly flattened at the ends by the pressure.									
Uniform pillar rounded at the ends } that the force might pass through } the axis }	60.5	1.75		.13	2141	2749		This was capped at the ends with iron to prevent them being crushed with the pressure. It bent and broke diagonally.									
Uniform pillar, one end rounded and } the other flat. Plate XV. No. 3, D. }	60.5	1.75		.09 .11 .13 .16 .20 .27 .48	2141 3197 3645 4541 5437 6333 7229	7229	6109	The rounded end was much crushed.									
Uniform pillar, one end rounded and } the other flat }	60.5	1.75		.06	1070				In this pillar the rounded end was capped with iron to prevent the end being crushed.								
				.08	1598												
				.11	2270												
				.15	2718												
				.17	3166												
				.19	3614												
				.23	4093												
				.32	4541	4989											
				Uniform pillar, both ends flat. Plate } XV. No. 3, E. }	60.5	1.75				4 10	.02 .09 .14	3335 4795 9499	10171 11179	9625	It was crushed at the end diagonally through the centre, and sunk down by flexure. No. 3, F.		
				Uniform pillar, both ends flat. Plate } XV. No. 3, E. }	60.5	1.75						2911 5467				This sunk by bending in the middle as usual; a portion of both ends was cracked.	
				Uniform pillar, both ends flat. Plate } XV. No. 3, E. }	60.5	1.75					.05 .09 .11	6139 1070	8323				With 8323 lbs. it sunk down by bending, and when unloaded had taken a permanent set of .52 inch.
				Uniform pillar, both ends flat. Plate } XV. No. 3, E. }	60.5	1.75					.03	3390						This deflection was taken along the side, but it sunk down diagonally, one end was slightly crushed. Most of these pillars changed the direction of flexure as they became loaded.
											direction altered.	.02 .04 .07 .14	4459 6811 8155 8827				8827
											Uniform pillar, flat at the ends, and } well-bedded }	29.75	1.75			2 7 1/2				13083	It was crushed at the ends with the pressure, which caused it to break with a less weight than otherwise.
Uniform pillar, flat at the ends, and } well-bedded }	30.25	1.75							14305		With less weight than this, no cracking at the ends took place; but with this, it wrinkled at the ends, bent and sunk down.						
Uniform pillar, flat at the ends, and } well-bedded }	48	1.75							9229		It was slightly bent before the weight was laid on; no cracking at the ends perceived before fracture by bending.						
Uniform pillar, flat at the ends.....	46.1	1.02	1 3/4			1791	1754	These generally bent diagonally without crushing at the ends.									
Uniform pillar, flat at the ends.....	46.1	1.02				1791											
Uniform pillar, flat at the ends.....	46.1	1.02				1679											
Uniform pillar, flat at the ends.....	46.1	1.50	2 13/4			8069	7888	In the first and second pillar there was no cracking at the ends previous to fracture. The last was slightly split at one end by drying, and failed there.									
Uniform pillar, flat at the ends.....	46.1	1.50				8049											
Uniform pillar, flat at the ends.....	46.1	1.50				7545											

Note.—By breaking weight above, is understood that which overcame the resistance of the pillar, and with which it sunk down.

TABLE XIII. (Continued.)

Red Deal.

Uniform Rectangular Pillars of Red Deal, flat at the ends, cut out of the same plank; each pillar being four feet ten inches long, and having the same weight, 3 lbs. 13 ozs., and nearly the same area of section, four square inches. The sections were as in Plate XV. No. 10.

No. of Experiment.	Ratio of sides of pillar.	Deflection.	Corresponding weight.	Weight with which it sunk down.	Remarks.
		inch.	lbs.	lbs.	
1.	1 to 1	·03 ·10 ·12 ·17	3254 6505 8857 11209		{ Bent in direction of diagonal, one end crushed about one inch from bottom; and in the middle, two-thirds or three-fourths of the area being crippled.
2.	1 to 1	·09 ·12 ·15 ·32	4153 6505 8857 11209	13385 Mean 11993 11601	
					Crushed as before.
3.	1 to 2	·13 ·17 ·25	4153 5329 6505	7681	Sunk by bending in the direction of the smaller side.
					{ In another experiment, a piece of the same size broke with somewhat less than this.
4.	1 to 3	·42	4153	4349	Sunk by bending in the direction of the smaller side.

EXPLANATION OF THE PLATES.

Fig. 1. Plate XIII. represents the lever and other apparatus used for breaking the pillars: it has been described in the commencement of this paper (Art. 2.).

Fig. 2. Plate XIV. shows the manner in which the pillars were subjected to a constant strain, to try the effect of time upon them (Art. 53.).

Figs. *a, b, c, &c.* to *n*, Plate XV. are the forms of the fractures from some of the solid pillars with rounded ends in Table I., the pillars as they appeared after fracture being drawn and placed over the forms of the fractures.

Figs. *o, p, q, r, s, t, u, v*, Plate XV. are the forms of the fractures from the shorter pillars with flat ends in Table II.; and the figures over them represent the appearances after fracture of the pillars they were obtained from, with marks upon the pillars, showing the places where they broke. All these sections are referred to in Tables I. and II. In many of these pillars there was a crack after fracture, showing the position of the neutral line; and in some, the compressed part broke off as a wedge, the form of which may be seen from the marks upon the pillars.

The groups of pillars, designated as No. 1, No. 2, No. 3, &c. Plate XV. are intended to represent the forms of the different cast-iron pillars broken, with marks upon them, showing where they usually broke. Those in No. 1, which may be considered as including the longer pillars in Tables I., II., V., represent three pillars of the same material, length and diameter, whose relative strengths are as 1, 2, 3, nearly.

No. 2. are pillars differing from those of No. 1, in having discs upon the flat ends, to give them a larger bearing; the results showing that a small increase of strength is obtained by that addition.

No. 4. represents the forms of the pillars in Tables VI. and VII., which generally gave strengths about one-seventh or one-eighth above those obtained from uniform solid pillars of the same length and weight. The marks upon them show where they usually broke.

No. 5. includes pillars formed to show the effect of defective fixing; a pillar so placed that the pressure would pass through the diagonal, bearing only about one-third of what it would have done if the ends had been pressed upon through their whole surface (Table XI.).

No. 6. The second pillar in this group is intended, by its section in the middle, to represent the connecting rod of a steam-engine; and experiment shows that it is very weak compared with a hollow cylinder of the same length, weight, and lateral dimensions (Table XI., Art. 48.). The first form of pillar in No. 6. gave strengths greater than the second, but still less than a hollow cylinder would.

No. 7. shows the relative diameters of the hollow pillars in Table VIII., broken with rounded caps upon the ends, the caps being shown near to the pillars.

No. 8. represents the hollow pillars in Table IX., broken, with their ends flat; the rings round the three first pillars given, show the manner in which some of these

were reduced, one half of the thickness of the metal being taken away from the pillar near to the ends, and one-fourth, half way between the middle and the ends. When no more metal than this was taken away, the pillars were never broken in the reduced parts. The fourth pillar given in this group was a very good casting, and the section is represented by W below it. The small piece where the crack is seen, broke out, showing very distinctly the position of the neutral line.

The pillars No. 9. are the first four in Table XI. They were hollow, and the metal in them was cast to be all of equal thickness, except that in the discs. The marks upon them will show the places in which they broke. These pillars were somewhat weaker than uniform hollow cylindrical ones of the same length, thickness and quantity of metal (Art. 48.).

The two last pillars in No. 3. were of oak (Table XIII.); and the second of these is intended to show how timber, when much compressed, becomes wrinkled near the ends.

In this Plate the pillars are not drawn of their real lengths, but many of them are of half the length compared with the diameter.

XXI. *On the Minute Structure and Movements of Voluntary Muscle.* By WILLIAM BOWMAN, Esq. Demonstrator of Anatomy in King's College, London, and Assistant Surgeon to the King's College Hospital. In a Letter addressed to ROBERT BENTLY TODD, M.D. F.R.S., Professor of General Anatomy and Physiology in King's College, London. Communicated by Professor TODD.

Received June 18,—Read June 18, 1840.

MY DEAR DR. TODD,

IN offering to your notice the following account of some researches into the minute structure and movements of voluntary muscle, which I commenced at your suggestion, and in the prosecution of which you have so materially aided me, I am encouraged to hope that some parts of the inquiry may not be altogether uninteresting to the Royal Society, to which the first discoveries in this important branch of physiology by ROBERT HOOKE and the illustrious LEEUWENHOEK were communicated, and which also possesses, in its later Transactions, important papers on the same subject.

It has long been known that voluntary muscle is susceptible of subdivision into minute threads, which being almost uniform in size, unbranched, and united by means of vascular and cellular parts into bundles of varying bulk, have generally been regarded as constituting the essential proximate anatomical element of the organ. All the best observers, since the time of LEEUWENHOEK, have recognised the existence of these threads, but their form and composition have been objects of continual dispute, and in the present day we seem to be as little advanced towards the determination of their real nature as ever. The improvements which have taken place in the construction of microscopes, appear indeed to have only afforded grounds for new differences of opinion, as may be seen by the records of the last few years. In 1837 Mr. SKEY, after an elaborate investigation, concluded that these threads were tubes containing a soluble gluten, round which were disposed, in longitudinal sets, still finer filaments, which in their turn were held together by circular bands or striæ; and since that period, Dr. MANDL, a microscopical observer in Paris, has described and figured them as bundles of fibrils, held together by a spiral coil of filamentous tissue. A more common opinion is, that these threads are bundles of beaded fibrillæ, whose beads being placed side by side, cause the appearance of transverse lines, a view which was first entertained by FONTANA, though his claims to it have been often overlooked. More lately Dr. SCHWANN and M. LAUTH have advocated the same doctrine, especially the former, who has adduced additional arguments in its support.

My design in the present paper is, *first*, to vindicate, under certain modifications,

the general correctness of this opinion, and to render more exact and ample the knowledge of its details; *secondly*, to point out the existence and properties of new parts which, as far as I can ascertain, have not yet been described; and *thirdly*, to elucidate the proximate cause of voluntary motion, by describing shortly the mechanism of certain movements performed by the elementary constituents of muscles.

In speaking of the threads already mentioned, it becomes necessary to attach to them a term of definite meaning. The words *fibre*, *fibrilla*, and *filament*, have been so much abused by indiscriminate application, that it would be confusing the subject to employ them in this sense; and though the term *primitive fasciculus*, adopted by FONTANA and some subsequent writers, will be shown in the sequel to be liable to considerable objections, as implying a composition by smaller fibrils, which can never be said to be a correct expression of the actual condition, yet I shall prefer its use to that of a new designation. The small component fibrils, into which the primitive fasciculus may usually be split up, will be styled *primitive fibrillæ*, or simply *fibrillæ*.

As even the configuration and bulk of the primitive fasciculi have not hitherto been fully ascertained, these points demand attention. Their shape may be briefly described as polygonal in all animals, though in some examples they approach very nearly to a cylindrical form. The examination may be conducted by obtaining either a longitudinal or transverse view of the parts; but the former, without precaution, is apt to lead to error. It is usual to place the recent fasciculi, moistened with water, between glasses, previous to inspection, whereby they become swollen from absorption of the fluid, and more or less altered towards a cylindrical figure. If this mode of examination be desired, it is requisite, therefore, either not to wet the object, or to moisten it with a fluid which is not absorbed, such as thick syrup. It will then be seen that the cross markings, called transverse striæ, with which every anatomist is familiar, as visible on the fasciculus, have not uniformly a straight direction across it, but are frequently all bent at an obtuse angle, along a certain line parallel to the margin, showing a sudden change in the aspect of the surface on which the striæ are seen. This appearance was not unobserved by FONTANA*, who in a figure of four fasciculi, has represented it more or less decidedly in all, and it has been observed by others. It is often so slight as at first to escape notice, and it is by no means constant. It is best seen when by an accident a fasciculus slopes from the observer, who, as he alters the focus, so as to bring different portions of it successively before the eye, gains partially such a view as would be presented by a transverse section. Now supposing the fasciculi to be polygonal, the frequent slightness or absence of this appearance may still consist with a uniformity of the configuration which occasions it, since if the fasciculus lie flat, and the observer regard it perpendicularly, as is generally done, he would want that perspective view which could alone disclose it. But besides this, it is easy to notice, as the object is being brought into focus, which part of it is first seen, as being the most prominent, and this is not always the central part. Moreover, as the

* FONTANA, *Traité sur le Venin de la Vipère*, tab. vi. fig. 6. 7.

glass descends, the obliquity of the surfaces may be ascertained by the more or less rapid extension of the field of vision on either side; and if irregularities occur in this respect, they can depend on no other cause than a varying inclination of the surfaces, or, in other words, on angularities of the fasciculus, and this circumstance I have uniformly remarked. Although the cut extremities of recent fasciculi are usually bruised and distorted by the edge of the instrument employed, I have sometimes accidentally obtained one, which, from the sharpness of its outline, seemed fairly to represent the real figure of the fasciculus, and this figure has been polygonal. On one occasion also, when examining muscle that had been macerated in liquor ammoniac, the section shown in Plate XVI. fig. 1. presented itself, which is the best of the kind I have met with in a wet specimen. On the whole, my examinations of recent specimens sanction the opinion that the fasciculi are in general far from being cylindrical, though occasionally approaching very nearly to that configuration.

It may be said, that the appearances above described are referrible to violence done to the soft and delicate texture of the fasciculus by the act of detaching it from the mass, but their constancy has convinced me that such is not the case; and indeed the form contended for is well designed for package, and is probably determined by the mutual pressure of parts, which have been formed and have increased together.

But the most conclusive evidence in favour of the polygonal form of the fasciculi, is to be obtained by examining a transverse section of a dried muscle, after causing it to reassume its original bulk by wetting it*. In such examples the fasciculi are, without any exceptions, found to be not cylindrical, but more or less flattened on several of their aspects, where they are in contact with the neighbouring ones, and this so irregularly, that it would be in vain to attempt a particular description of their forms. An idea will be best conveyed by a reference to the illustrations (fig. 3 to 8.), in which it will be seen that the sections present almost every variety of figure that can be inclosed by from three to six or more sides. In some examples, most of the angles are sharp and decided, while others are rounded off, so as to leave spaces between the contiguous fasciculi, often for the passage of vessels. In other instances, most, or all of the fasciculi have the angles so much rounded, that they are not very much removed from the cylindrical shape. These are by far the least common, and I have only met with them in birds. In insects, the fasciculi are often flattened bands. (Fig. 2. Staghorn Beetle.)

The primitive fasciculi vary considerably in bulk in different classes and genera of animals, and even in the same animal and the same muscle. In the course of my inquiry I have noted down the average diameter of the fasciculi in the specimens examined; and in the following Table, examples of these measurements are exhibited. It is to be observed, that where the admeasurement is single, it is an average of many, and two numbers denote the extremes met with.

* This plan was long ago adopted by LEEUWENHOEK and PROCHASKA, as well as by others.

TABLE.

		Diameter of primitive fasciculi in fractions of an English inch.	Average diameter of same in the class.
HUMAN	Adult male, ordinary size	$\frac{3}{16}$	Males average $\frac{3}{16}$ Common average $\frac{3}{16}$ Females average $\frac{3}{16}$
	Another male, ordinary size	$\frac{3}{16}$ to $\frac{1}{8}$	
	Another male, very muscular	$\frac{3}{16}$ to $\frac{5}{16}$	
	Adult female, ordinary	$\frac{3}{16}$ to $\frac{3}{8}$	
	Another female, ordinary	$\frac{3}{16}$ to $\frac{5}{16}$	
OTHER MAMMALIA	Mole (<i>Talpa europæa</i>)	$\frac{7}{16}$ to $\frac{3}{8}$	$\frac{3}{16}$
	Dormouse (<i>Myoxus avellanicus</i>)	$\frac{7}{16}$ to $\frac{5}{8}$	
	Cat (<i>Felis domestica</i>)	$\frac{1}{16}$ to $\frac{3}{16}$	
	Mouse (<i>Mus</i>)	$\frac{1}{16}$	
	Pig (<i>Sus Scrofa</i>)	$\frac{3}{16}$	
	Horse (<i>Equus</i>)	$\frac{1}{16}$ to $\frac{3}{8}$	
	Rabbit (<i>Lepus Cuniculus</i>)	$\frac{3}{16}$ to $\frac{5}{16}$	
	Hare (<i>Lepus timidus</i>)	$\frac{7}{16}$ to $\frac{3}{8}$	
	Cow (<i>Vacca</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Sheep (<i>Ovis</i>)	$\frac{3}{16}$ to $\frac{3}{8}$	
BIRDS	Owl (<i>Strix flammea</i>)	$\frac{1}{16}$ to $\frac{3}{16}$	$\frac{3}{16}$
	Chaffinch (<i>Fringilla Calebs</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Redpole (<i>Linaria vulgaris</i>)	$\frac{1}{16}$	
	Turkey (<i>Meleagris Gallipavo</i>)	$\frac{7}{16}$ to $\frac{3}{8}$	
	Heron (<i>Ardea cinerea</i>)	$\frac{1}{16}$ to $\frac{3}{16}$	
REPTILES	Teal (<i>Querquedula Crecca</i>)	$\frac{7}{16}$	$\frac{3}{16}$
	Frog (<i>Rana temporaria</i>)	$\frac{1}{16}$ to $\frac{1}{8}$	
	Newt (<i>Triton palustris</i>)	$\frac{7}{16}$ to $\frac{3}{8}$	
	Lizard (<i>Lacerta agilis</i>)	$\frac{3}{16}$	
	Gecko (<i>Gecko</i>)	$\frac{3}{16}$	
	Crocodile (<i>Crocodylus vulgaris</i>)	$\frac{3}{16}$	
	Boa (<i>Boa</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Viper (<i>Vipera Berus</i>)	$\frac{3}{16}$	
FISH	Sturgeon (<i>Accipenser Sturio</i>)	$\frac{1}{16}$	$\frac{3}{16}$
	Skate (<i>Raja Batus</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Paracuhu (large river fish of Guiana)	$\frac{3}{16}$	
	Halibut (<i>Pleuronectes Hippoglossus</i>)	$\frac{3}{16}$	
	Whiting (<i>Gadus Merlangus</i>)	$\frac{1}{16}$	
	Cod (<i>Gadus Morrhua</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Salmon (<i>Salmo Salar</i>)	$\frac{3}{16}$	
	Sprat (<i>Clupea Sprattus</i>)	$\frac{3}{16}$ to $\frac{1}{8}$	
	Flying Fish (<i>Exocoetus volitans</i>)	$\frac{7}{16}$ to $\frac{1}{8}$	
	Eel (<i>Anguilla vulgaris</i>)	$\frac{3}{16}$	

TABLE. (Continued.)

		Diameter of primitive fasciculi in fractions of an English inch.	Average diameter of same in the class.
INSECTS	Staghorn Beetle (<i>Lucanus Cervus</i>) ..	$\frac{3}{16}$ to $\frac{1}{10}$	$\frac{1}{10}$
	"Water Scorpion" (<i>Nepa cinerea</i>) .	$\frac{1}{80}$	
	"Water Spider" (<i>Gerris lacustris</i>) .	$\frac{1}{16}$	
	"Harry Longlegs" (<i>Tipula</i>)	$\frac{3}{80}$	
	<i>Carabus nemoralis</i>	$\frac{3}{16}$ to $\frac{1}{7}$	
	"Blue Bottle Fly" (<i>Musca vomitoria</i>)	$\frac{1}{16}$ to $\frac{1}{80}$	

From this it would appear, that the average diameter of the fasciculi in the Human female is upwards of a fourth less than in the male, and that the average of both together is greater than that of other Mammalia. The class of Fishes has fasciculi nearly four times the thickness of those of Birds, which present the smallest of all. Next to Fish come Insects, then Reptiles, then Mammalia. In each of these different classes an extensive range of bulk is observable, some fasciculi being three, four, or more times the width of others. In the above measurements, precautions have been taken to include only specimens in an uncontracted state, the importance of which will be seen in the sequel.

Of the Transverse Striæ.

A decisive characteristic of voluntary muscle consists in the existence and close arrangement of alternate light and dark lines, discoverable only by the microscope, and of exquisite delicacy and finish, taking a direction across the fasciculi. These lines are so uniformly present, both in recent muscle and in that which has been preserved, either by drying, or in alcohol, solution of alum, corrosive sublimate, or in various other ways, that it is most important to understand correctly their real nature. Their existence was doubtless known to HOOKE, and LEEUWENHOEK has given more than one very accurate description of them, as well as made constant reference to them in his letters. He believed, during the earlier years of his inquiry, that they were circular bands or girths, surrounding a bundle of fibrillæ; but at a later period he regarded them as of a spiral shape, and endeavoured to show, by a fancied analogy with an elastic coil of wire, that they were in some manner the originators of motion. PROCHASKA seems to have considered them to arise from a series of minute flexuosities of the fibrillæ, caused by impressions made upon these by the contact of the filamentous and capillary tissues, which he fancied to penetrate into the interior of the fasciculi and invest each fibrilla. But in endeavouring to sustain an erroneous hypothesis of muscular action, he deceived himself into the opinion that these so-called flexuosities were the same, in kind, with secondary inflexions of the whole fasciculus, and with those zigzag bendings to which PREVOST and DUMAS have in later

years called the attention of physiologists, and thus their real structure eluded him*. FONTANA was the first to give what has seemed to me to be the correct explanation of their nature, where he says, "*Les fils charnus primitifs (prim. fibrillæ) sont des cylindres solides, égaux entr'eux, et marqués visiblement à distances égales de petits signes, comme d'autant de petits diaphragmes ou rides. Je n'ai pu appercevoir dans ces fils une marche vraiment ondulée et il m'a paru que les petites taches curvilignes du faisceau primitif étaient formées par les petits signes ou diaphragmes des fils charnus primitifs†.*"

It is difficult to conceive how the striæ should have escaped the observation of Sir E. HOME and Mr. BAUER, when investigating the structure of muscle, but such seems to be the fact. In the last ten or fifteen years, during which so much more attention has been given to microscopical researches, various observers have noticed them, and attempted to explain their composition. Among these, Dr. HODGKIN and Mr. LISTER describe them, but offer no opinion as to their nature. Dr. SCHWANN adduces several reasons for thinking them formed by the lateral parallelism of the beads of contiguous fibrillæ‡. MÜLLER adopts this explanation, and M. LAUTH holds the same view§. Mr. SKEY, in the Philosophical Transactions for 1837, advances a directly opposite opinion. He says that the fibres (primitive fasciculi) are in reality tubes, containing a soluble gluten, round which the fibrillæ are arranged in sets; that these are finally surrounded, bound together, and retained in their position by the transverse striæ, "which are the woof to the warp of the longitudinal filaments, but instead of being interlaced with them, they form circles around, and attached to the most prominent part of the longitudinal filaments, to which they are intimately united." (p. 375.) Lastly, so lately as 1839, M. MANDEL, speaking of the primitive fibrillæ, avows the following opinion: "*Les fibres élémentaires sont réunies dans une gaine qui est striée à sa surface, et l'ensemble de cette gaine et des fibres élémentaires constitue les faisceaux élémentaires, qui sont les parties élémentaires des muscles. Voici le résultat de nos recherches sur la structure de cette gaine. Les lignes noires (dark transverse striæ) ne sont, selon nous, que les bords des lignes blanches (light transverse striæ): ces lignes blanches sont les filets du tissu cellulaire qui enveloppe sous forme de spirale les fibres élémentaires, et forme de cette manière la gaine||.*"

It will at once appear from the preceding statements, that the nature of these

* "*Quod causam istarum rugarum quæ tum in fasciculis fibrarum muscularium (Lacerti), tum in fibris muscularibus ipsis (prim. fascic.), et filis carnis (prim. fibrillæ) observantur concernit, id jam in principio hujus capituli attigi, ubi dixi, a filis cellulosis, arteriis, venis, et nervis, fasciculos fibrarum muscularium decussari, et alternatim sæpe ita stringi, ut in serpentinos flexus agantur; idem fit in fibris muscularibus et filis carnis, quæ simili prorsus modo a filis cellulosis, vasculosis, et nervis percurruntur et decussantur.*"—PROCHASKA, De Carne Musculari, Viennæ, 1778, cap. iv. sect. i.

† Traité sur le Venin de la Vipère, p. 229.

‡ MÜLLER's Phys. as translated by BALY, p. 880.

§ L'Institut, No. 70, 1834.

|| Traité pratique du Microscope, Paris, 1839, p. 74-5.

markings is yet a matter of dispute among those who have the most carefully studied this subject, and therefore that a new examination and new facts are required to determine it. Enough has also been said to show that their nature cannot be ascertained without elucidating the composition of the whole fasciculus, a circumstance which induces me to make the following discussion subservient to explain the general construction of this proximate anatomical element of muscle.

In the first place, it is to be remarked, that no doubt seems to exist as to the fact, that when alternate light and dark spaces are seen on individual fibrillæ, detached from the mass, they are precisely equal in width to the light and dark striæ on the fasciculus from which they have been withdrawn. There is therefore an evident correspondence in this respect, between the striæ on the fasciculus and the markings on the fibrillæ, a correspondence which is so exact, that it is reasonable to believe the appearance must be the result of the same cause in each condition; and either that the striæ must be formed by the coaptation of the markings on neighbouring fibrillæ, or that these markings must be impressions received from the investing striæ, as from a distinct and independent structure. Which of these alternatives is the correct one, I shall now attempt to show.

It is to be observed, that the latter supposition entails one of two consequences worthy of being traced; either those filaments only can receive markings which are at the surface of the fasciculus, or, if it be proved that all are marked, all must be at the surface, and the fasciculus must be of the nature of a tube. But both such consequences would be at variance with fact; for there will be no difficulty in proving all the fibrillæ of a fasciculus to be thus marked, and the fasciculi to be not tubular, but composed of a solid bundle of fibrillæ.

First, *all the fibrillæ are marked.* If a muscle that has been macerated in a cool place be examined, the fibrillæ will generally be found to fall readily asunder, and float in great numbers about the field of the microscope; all these fibrillæ present the dark and light spaces alluded to; there are none without them. Under the same circumstances fasciculi will offer themselves in a variety of conditions, partially separated into their elementary fibrillæ, either at their extremities or centres; and wherever the fibrillæ can be clearly distinguished, where their texture has not been destroyed by the macerating process, they will exhibit these alternate dark and light points with more or less distinctness. This appearance is often particularly well displayed in the tissue of the heart, which, though its minute structure is not at present under discussion, I may remark, has decided striæ, doubtless produced in the same mode as those of voluntary muscle. The heart (figs. 12 and 17.) often exhibits in a decided manner the marked structure of the primitive fibrillæ, for it seems to separate by maceration or otherwise, rather into irregular masses of fibrillæ, than into primitive fasciculi, similar to those of voluntary muscle. Hence a fragment of it has no determinate form; the fibrillæ composing it are broken off at various lengths, some projecting more, others less; and it is easy to bring into focus successively all

the parts of this very irregular surface, and even at its ends to examine fibrillæ which stand out from its central portion. All these fibrillæ are marked by the alternate light and dark points.

It has occasionally happened, especially in the case of muscles with bulky primitive fasciculi, that in the manipulation with needles, preparatory to examination, a recent fasciculus has been partially wounded, so that its interior is displayed. A specimen in this state is presented in fig. 9, from the Boa. The fibrillæ here seen are all marked. This fact proves that marked fibrillæ exist in the interior of the fasciculus, and is not at all controverted by the circumstance that sometimes the surface of such a laceration does not show a structure of this kind, the violence inflicted by the instrument being sufficient to account for the destruction or mutilation of parts of so much delicacy.

If further evidence be wanting, it may be drawn from the writings of authors. It is highly probable that Hooke*, when he hinted to the Royal Society that "he knew of a method of making succedaneous muscles, to give one man the strength of ten or twenty if required," had in view these marked fibrillæ, which he thought a series of bladders. PROCHASKA† was so certain that the fibrillæ were marked, or as he thought flexuous in the interior of the fasciculus, that he framed a false hypothesis to explain it, imagining that vessels, nerves, and cellular tissue penetrated within the fasciculi, and twining among the fibrillæ, so impressed them. FONTANA, as has been seen, believed the fibrillæ to be all marked; and it will be difficult to find any one of the older anatomists who had seen detached fibrillæ, and who noticed them to be cylindrical, except perhaps Muys‡, who represents them in one of his figures. DR. HODGKIN and Mr. LISTER make no mention of having seen primitive fibrillæ, at any time, separated from the fasciculus, nor do they offer any remark as to what they

* "On April 25, 1678, he showed an experiment further to explain the action of a muscle, which was by a chain of small bladders fastened together, so as by blowing into one pipe the whole might be successively filled, and by that means contracted, supposing the fibres of the muscle, which seemed like a necklace of pearl in the microscope, might be filled with a very agile matter, which he thought most likely to be air, which being included in so thin skins, was easily wrought upon by heat, cold, or the acting properties of the liquor that pass between them, and so perform the lengthening and contracting of the muscles."—Posthumous Works by WALLER, 1707. Life, p. 20.

In a letter from LIEUWENHOEK to OLDENBURG, August, 1682, he says, that the fibres of flesh are composed of globules or particles nearly approaching the globular figure, of which he supposes 1,000,000 would not equal a grain of sand. He afterwards explains, however, that he calls by the name of globules all the particles of which flesh, fat, bone, hairs, &c. are composed, which makes it probable he had then no clear conception of the beaded structure of muscle.—Experiments and Observations of ROBERT HOOKE and other eminent virtuoses of his time, by W. DERHAM, F.R.S., 1726.

† PROCHASKA says of the blood-vessels, "Sic ergo ex vaginâ musculi communi per ejus septa intra musculi substantiam usque inter fila carnea conducuntur. In hoc decursu continuo crescit ramorum tenuitas ac numerus, ita ut fibræ musculares (prim. fasc.) non tantum, sed etiam fila carnea (prim. fibrillæ), totâ suâ longitudine arterioli circumdata et decussata sint." And of the nerves, "Suo decursu et ramificatione arterias propemodum imitantur."—De Carne Musculari, sect. i. cap. v.

‡ MUYS, Investigatio Fabricæ, quæ in partibus Musculos componentibus exstat: Lugd. Bat. 1741. 4 tab. 1.

conceive their form to be, further than observing that no trace of globular structure can be detected. Mr. SKEY, however, believes the primitive fibrillæ to be "uninterrupted threads or cylinders," only "occasionally exhibiting on their surface the marks or indentations corresponding to the distance between the circular striæ on the whole fibre*:" and he supports his opinion by several considerations which demand a distinct examination. He says, in proof that the fibrillæ receive their marks from the striæ, "I think the filament will present the more or less distinct appearance of a globular structure in proportion to the distinctness of the circular striæ:" but it is clear this might be adduced with precisely equal force the opposite way. Mr. SKEY argues for the cylindrical form of the fibrillæ, by denying the existence of the reputed globules of Sir E. HOME and Mr. BAUER, and by proving the fibrillæ to be three times finer than a blood-globule. Now, as to the globules of Sir E. HOME, few who have examined the subject, and attentively perused his papers, can doubt that that physiologist was deceived on this subject, since the fibre which he saw, and compared under the microscope with a string of blood-globules, was nearly as large as many examples of the primitive fasciculi, and very much greater than a primitive fibrilla, of the existence of which he seems to have been ignorant. It is therefore erroneous to say, as has frequently been done, that the theory of a beaded structure of the fibrillæ originated with, or was supported by him. He advocated the existence of a beaded tissue, but not such as I believe to exist in nature. To point out his fallacy, therefore, is not to overturn what is here contended for. And with regard to the proportion in size which such beads or particles may chance to bear to the globules of the blood, it is a question long ago set at rest by LEEUWENHOEK and MUYS, the latter of whom gives accurate relative admeasurements of these parts, and points out their disparity. It is a point, too, which cannot determine the question, since no necessity has been or can be shown why the beads of muscle should conform to the size of the blood-globules, or even of their nuclei. But Mr. SKEY's most pointed argument is this: "That in the Cod and Haddock, in which the striæ are of extreme beauty and delicacy, the ultimate filaments present no appearance of a globular arrangement, but are distinctly continuous and uniform throughout their whole length." Yet even granting this fact to be substantiated, it would scarcely invalidate the strength of the arguments above advanced, which speak to positive appearances. However, having been led to make the muscles of these fishes an object of special study, I am not able to confirm Mr. SKEY's remark, but have found their flesh to present the same characters with that of others of the same class, many of which have been also made the subject of observation, as the Skate, Whiting, Halibut, Salmon, &c. The most obvious microscopic characters of these seem to be the following. The primitive fasciculi are large and nearly transparent, so that when highly magnified their aspect is not unlike that of glass. This, as might be supposed, is shared with them by the muscle of many Crustacea. The fibrillæ are in general distinguished by longitu-

* Philosophical Transactions, 1837, p. 376.

dinal lines, taking the direction of the fasciculi, these lines being here and there exceedingly strong and decided, and leaving but a very narrow light streak between them. In other parts they are fainter, but always parallel, unless the fibrillæ are bent by violence from their course, in which case they seem to be easily disarranged, as though their lateral connexion with one another were but slight. The striæ upon these fasciculi are very delicate, and quite regular, if the parallelism of the fibrillæ be preserved; but where this is disturbed, the striæ are, as it were, broken to pieces, and the individual fibrillæ which they crossed, bear upon them the disarranged fragments of the markings of which they consisted. Either the striæ or these markings are everywhere clearly visible, except about the very thick longitudinal dark lines described, where they are always faint, sometimes undistinguishable; a fact which seems sufficiently explained by the presence of those lines absorbing and obscuring by their depth the very delicate striæ that cross them at right angles; and except also where a slight and irregular obliquity of the fibrillæ causes so complicated an interference of the longitudinal lines among the cross markings of each, that these last, being the faintest, are only here and there apparent*. The fibrillæ, however, are in general readily spread abroad at the extremity of a fasciculus, and there uniformly, when not too much injured or obliquely overlapping each other, present the markings well defined. Indeed, some of the most beautifully marked fibrillæ that I have seen have been such as I now speak of, hanging out from the end of a fasciculus taken from one of these fishes. In these also, as in other animals, I have frequently by accident obtained a view of the interior of a fasciculus, and observed every fibrilla to be marked. By maceration it is not difficult to obtain the fibrillæ entirely detached, and in these the correctness of Mr. SKEV's remark may seem at first sight to be partially borne out, for in many of them it is impossible to detect any appearance of a marked structure. In many others, on the contrary, this structure is evident enough; and by attention to the mode and degree of illumination, I have frequently succeeded in discerning the regular markings, though very faint, on fibrils which appeared before to be decidedly cylindrical. The fact seems to be, that in these fishes the distinction between the light and dark points is not so clear as in most other cases; and their colour being at the same time very light, the extreme tenuity of the ultimate fibrillæ does not always allow of their showing individually the markings, which are visible enough when in juxtaposition with one another. It may therefore be concluded, that they form no exception to the general fact, that all the fibrillæ of voluntary muscle possess the markings which we are now considering.

Secondly, *the fasciculi are not tubular, but consist of a true bundle of fibrillæ*. In the preceding observations a certain amount of proof has been offered in illustration of this point; it having been shown that accidental wounds frequently display the interior of the more bulky fasciculi, and demonstrate their composition by fibrillæ;

* These appearances, though in a less degree, are not uncommonly seen in disturbed fasciculi of the muscles of other animals, and they are undoubtedly very deceptive.

but as many persons are apt to be sceptical as to the credibility of the results of researches of this nature, with whatever uniformity obtained, it is necessary as well as interesting to corroborate every observation by others, in which the same structure is brought into view under a variety of aspects. In a subsequent part of this paper some circumstances will be mentioned, relating to the effects produced on the fasciculi by the presence of chemical agents, which are only explicable on the present supposition, but as it would be premature to introduce them here, the same thing may now be proved in another way.

It is easy for any one to satisfy himself that the fasciculi are not tubes, by the most decisive of all methods, the making a transverse section; and it is strange that an operation so simple, which was practised by both LEEUWENHOEK and PROCHASKA*, should have escaped the attention of some later inquirers. Such a section never presents the slightest appearance of any central cavity. I had made several transverse sections of dried fasciculi, however, before discovering in them any decided trace of the extremities of cut fibrillæ, and concluded that in the process of drying, these had been so modified or united together, as to render them incapable of being individually distinguished; for the addition of a little citric acid would frequently expand the section and give its surface a minute mottling, such as I was willing to fancy might depend on the structure in question. These first observations were made on the flesh of Mammals, and I now attribute the indistinctness of the fibrillæ to their close and intimate lateral union, whereby they seem in this class to be generally the most reduced to the condition of a solid mass. But continuing to examine specimens derived from various sources, I was gratified by meeting at length with several which afforded the most ample confirmation to the views here adopted. The cut extremities of the fasciculi presented themselves as areas of an angular shape, more or less densely filled with minute dots, which are manifestly the ends of the fibrillæ. In Birds more especially, but also in Fish and Reptiles, I have met with such appearances with great uniformity; and in figs. 3 to 8. are accurate representations from each of these classes. The dots seem to be the extremities of solid threads. They have no central area distinct from their circumference, and the shadow occasioned by the image of a part of the window-frame in the field of the microscope, will throw one half of each of them into darkness. It is in this manner only that they can sometimes be brought into view at all. In Fish (figs. 3. 4.) the sections of the fasciculi are very ample, and filled up by very fine and closely-set fibrillæ, presenting their extremities to the observer. Some of these fibrillæ are more distinct than the rest (fig. 4.). In many fasciculi the fibrillæ are not individually apparent, the whole surface being merely uniformly and finely mottled. In Reptiles (figs. 5 and 6.), the specimens exhibit more or less plainly the ends of the fibrillæ composing the fasciculus. In Birds (fig. 7.), the

* PROCHASKA gives a figure of a transverse section of fasciculi in which the extremities of the fibrillæ are seen.

fasciculi are small, and more cylindrical, and the fibrillæ appear larger and more distinct from one another than is generally the case in the other classes. Some of the areas are larger, more transparent, and less densely filled with dots than the others. In Mammalia, as already stated, the surface is generally nearly uniform, though often finely mottled; but I have occasionally met with specimens in which the extremities of the fibrillæ were very visible. From the human subject, an example of this kind is selected (fig. 8.). In specimens in which the fibrillæ appear separated from one another, no connecting material having an evident structure has been observed. The addition of acid serves materially to increase the distinctness of the fibrillæ, an effect apparently due to its widening the interstices between them.

Having now shown that the existence of the striæ, as an independent structure, would entail consequences not in accordance with my observations, I pass on to an important circumstance corroborative of the view of their nature herein adopted, merely pausing to remark, that no writer who has believed the separate existence of the striæ, has ever given, or attempted to give, a genuine representation of them copied from nature, detached from the structures to which they are said to be connected, and that until this be done, the proof of their existence as an element of muscular organization, must be allowed to be deficient.

Now if it be true that these cross markings are the effect of an adaptation side to side of the beads of contiguous fibrillæ, and that these fibrillæ compose the whole thickness of the fasciculus, it is obvious that the striæ ought to be found not at the surface alone, but throughout the whole interior of the fasciculus; and this is rigorously the case. Owing to the transparency of the fasciculi, it is perfectly easy, under a high power, to bring into focus whatever portion of their interior the observer may choose. On bringing the surface nearest to him first into view, the points noticed early in this paper usually present themselves, and as the focus descends into the interior, the striæ seem commonly to undergo a slight lateral motion, but continue to be perfectly well defined, until at length they gradually become less clear, or are suddenly lost, according to the thickness of the object. The slight motion sideways, which is so very generally observed, is of course merely a deception resulting from the striæ seen in succession at any one point not being all precisely in a plane vertical to the observer, but slanting one way or the other from him, so that the focus in following the slant seems to move aside. Though I am not aware that this remarkable fact, of the existence of the striæ throughout the fasciculus, has hitherto been noticed by anatomists, it appears to me not only to be solely explicable by considering the striæ merely an appearance occasioned by the lateral cohesion of a bundle of marked fibrillæ, but also, in its turn, to be a proof amounting to demonstration, that such is in reality their nature. As far as my experience goes, it is uniformly to be observed wherever the striæ are distinct, and it will be decisive in proportion to the transparency and bulk of the fasciculus. Moreover, if the fibrillæ happen to have

been partially or quite deranged, so that their segments no longer conspire to form striæ, but are visible in separate longitudinal rows, these characters are visible in the interior as well as on the surface, and are not lost till the focus passes beyond the object on the opposite side.

It will follow from the view of the striæ now taken, that they are in truth the edges or focal sections of plates or discs, arranged vertically to the course of the fasciculi, and each of which is made up of a single segment from every fibrilla. The connexions between contiguous discs, are at least as numerous as the fibrillæ, and consist of those parts of the fibrillæ which connect their segments into one thread. Whether these are the whole attachments, I have not yet succeeded in satisfying myself. That there are also special means of connexion between the segments of contiguous fibrils, whereby the discs are more or less compactly constructed, is very evident from the regularity with which the fibrillæ maintain their apposition with one another; and it is not a little singular that this should have attracted the attention of anatomists to so small an extent as it seems to have done. This is also proved by phenomena observable in contraction, which will be hereafter described. What these means of connexion may be, however, it is by no means easy to determine. My observations have not led me much further than to enable me to point out some examples in which this adhesion was exceedingly strong, and others where it was so slight, that all trace of striæ was almost sure to be obliterated by the mere act of severing the fasciculi from one another. For instance, muscles in maceration present great variety as to the facility with which they divide into the elementary fibrils, and sometimes their union is so intimate as to permit complete disorganization rather than such separation. But in recent specimens there is a similar variety even more striking in degree. The primitive fasciculi, by traction on their extremities, usually break off short, the line of fracture not appearing to pertain more to the direction of the fibrillæ than to that of the striæ; and there is generally a slight derangement of both these in its immediate neighbourhood. Sometimes, however, the fibrillæ project in considerable numbers, as a lash, from both extremities of the fracture, many detaching themselves completely, and floating separately around. Here their lateral adhesion is exceedingly slight, and seems to be diminished by contact with water. The best specimens of this kind are from birds, which also afford the most characteristic transverse sections; and the one fact is strikingly confirmatory of the other, for I conceive it to be owing to the slightness of the connexion between the fibrillæ, that in the latter case these appear so isolated and distinct. On the other hand, it is not uncommon for the fasciculi to evince a disposition to split in the direction of the striæ, so that occasionally they break off quite square, or when pulled at their ends, crack partially across at several points, in lines corresponding to the striæ: this is seen in the case of the Pig (fig. 21.). Or several contiguous striæ may be thus separated from one another, as Mr. SKAY has well represented*, and as I have not un-

* Philosophical Transactions, 1837, Plate XIX. fig. 5.

frequently seen. An example of this from the Human subject is given in fig. 22. Lastly, the plates, of which the striæ are the edges or sections, may be detached entire, as *discs*, presenting no evidence of being formed of segments of fibrillæ. Fasciculi thus splitting have no longitudinal lines whatever, so intimate is the union of their fibrillæ. The striæ, on the contrary, are finely developed. Such, however, are not very often met with. Some examples are figured (figs. 23. 24. 25. 26. 27.), one from the Sprat, procured while in a recent state, and others from a Lizard which had lain long in spirit. In these instances, the segments of the fibrillæ were united into discs of so compact a texture, that their surfaces presented little or no appearance of their component particles; and they were, on the contrary, so transparent, that a careless observer might have imagined them to be mere rings. One of the most illustrative specimens of the lateral adhesion now spoken of, occurred in a rabbit newly born, which had been kept for some months in spirit. The parts being in progress of development, seemed to have undergone a partial natural dissection. A mass consisting of two or three fasciculi was lying in a curved form along the field, and presented on its convex border transverse series of beaded segments two or three deep, which, by the curve given to the part, had lost their longitudinal, but retained their lateral adhesion. They therefore stood out in relief, in the manner represented in the drawing (fig. 10.). Many segments of these outermost fibrillæ are completely detached.

From what has now been advanced, it is clear that the idea of the composition of the fasciculi by fibrillæ requires considerable qualification. They split up, indeed, in general into fibrillæ, but in other cases their natural cleavage is into discs, and in all instances these discs exist quite as unequivocally as the fibrillæ themselves. In fact, the primitive fasciculus seems to consist of primitive component segments or particles, arranged so as to form, in one sense, fibrillæ, and in another sense, discs; and which of these two may happen to present themselves to the observer, will depend on the amount of adhesion, endways or sideways, existing between the segments. Generally, in a recent fasciculus, there are transverse striæ, showing divisions into discs, and longitudinal striæ, marking its composition by fibrillæ. The reason why the transverse striæ are ordinarily so much more decided, is that the fibrillæ are more close together than the discs, and their shaded interspaces consequently narrower. The adhesion of the segments to one another is, in neither direction, fixed and rigid, but of a kind admitting, as will be afterwards seen, of those minute changes of position, which occur during the active state of the organ. The diversity now observed between the longitudinal and transverse union of the segments, may bear reference to the difference in the range of these motions in the two directions, that in the longitudinal being the more extensive*.

* Since writing the above I have met with the following remarkable passage in a recently published Croonian Lecture by JOHN HUNTER, which I give without comment.

"I do suppose that a muscular fibre is not one uniform body from end to end, but is made up of parts

Having endeavoured to prove the nature of the transverse striæ, and the general construction of the fasciculi, I next proceed to inquire more particularly into the nature and form of the minute segments of the fasciculus already spoken of. In doing this, it will be the most convenient to consider them as they appear when united into fibrillæ, this being the form under which they commonly present themselves, and under which it has been customary to regard them. Many attempts have been made to ascertain their nature, but as it appears to me without sufficiently attending to the following circumstance; That in consequence of the original and close union between contiguous fibrillæ, not one can be separated from the mass without suffering an unnatural mutilation of some parts of its surface; a mutilation which may have an influence on the form it may seem to possess. This source of ambiguity is such as to dispose me to receive with considerable hesitation the representations of primitive fibrillæ furnished by authors; and the few observations which here follow on this subject are offered with great diffidence. MÜLLER describes the fibrillæ as presenting "a regular succession of bead-like enlargements, which are somewhat darker than the very short constrictions which intervene between them*." Dr. SCHWANN, as quoted by the same eminent physiologist, gives a similar account, while Mr. SKEY considers the "light to be the elevated striæ, and the dark intervening lines the depressions;" but with respect to the relative width of the dark and light spaces and striæ, it seems to be agreed that the dark are the narrower. In my examination of the several parts, I have been led to imagine a fallacy to lie in supposing any absolute diversity in their colour. They appear to be rather an effect of a difference in form, or probably sometimes in density alone, between the alternate points of the fibrillæ. There does not seem to be anything in their appearance at variance with such a supposition, since if a rod of glass formed out of beads be held to the light, the beads are distinguished by dark circumferences, and by broad dark bands between them, which will vary with the inclination of their surfaces and the length of the intervening spaces, and would besides be much assisted if the connecting portions were of a less refractive material. Moreover, if two such rods be placed in contact, bead to bead, one behind the other, and then regarded between the observer and the light, the dark circumferences of the beads, at the margin of the rod, will be found to have vanished, the intervening bands being reduced to transverse lines or septa, or, in a word, the elements of striæ. I have had an instrument of this sort constructed, which may be regarded as a very imperfect model of a primitive fasciculus, and which

which may be called the component parts of a muscular fibre; and I am apt to suppose that a change takes place in the position of those parts during contraction, and this alteration diminishes the extent of those parts in one direction, while it is increasing them in another, although from the experiments it appears not to be in the same proportion; but what that attraction is, I shall not pretend to determine."—Croonian Lecture on Muscular Motion, No. V., year 1781. HUNTER's Works, PALMER's Edition, vol. iv. p. 261.

* Physiology, translated by BALY, p. 879.

is evidence of an interesting kind that the fibrillæ are beaded, and the striæ formed in the manner here above contended for. The light and dark points of the fibrillæ are capable of being reversed by varying the focus, which shows that they are an appearance occasioned by refraction, the phenomena being precisely those presented by the beaded vibrio, which they often nearly resemble in form as well as size. On the whole, little doubt remains on my mind that the fibrillæ consist of a succession of solid segments or beads, connected by intervals generally narrower, and I believe the beads to be the light, the intervals the dark spaces, when the fibril is in exact focus. Considerable variety is to be met with in the relative size of these two parts, but generally they are nearly alike. When there is a difference, it is commonly in favour of the light. In the accompanying sketches of various specimens of fibrillæ, it will be seen that the segments are by no means all of one form. In the new-born Rabbit they present the oval figure, the long diameter of each being in some examples parallel to the fibrillæ, in others oblique. The striæ formed by these last are also seen (fig. 10.). In the Chameleon the same thing is observed (fig. 14.). In the ocular muscle of a fish, there is an appearance of the beads overlapping, and of a lozenge shape (fig. 11.). In the heart of the Turtle the long diameter of the beads is across the fibrillæ (fig. 12.). The psoas muscle of the Hare presented several fibrillæ, in which the beads were further apart than usual, and of an oval form. In one state of the focus they were altogether light, and the intervals wholly dark; but in another, the beads were surrounded by a thick circumference of shadow, and a light streak appeared in the centre of the dark interval (fig. 15.), an appearance precisely similar to that which I have observed to take place in beaded rods of glass with elongated intervals*. In endeavouring to carry my investigations further into the intimate structure of these fibrillæ, I have hitherto been completely baffled; nor does the subject encourage very sanguine hopes as to the event of such a search, at least without higher powers of the microscope than we at present possess. From the sections, however, already described, and especially those of the fasciculi of Birds, the fibrillæ seem plainly to possess a circular transverse outline.

From such varieties in the fibrillæ, it is not wonderful that corresponding ones in the striæ should result, and some of the most remarkable met with since the com-

* It is not intended to be implied that the above varieties are peculiar to the several animals from which they are taken, or that in these animals similar appearances will uniformly be met with. On this subject (that of form), a much more extended inquiry is requisite, and I would again express my dissatisfaction with the above observations, as being made on detached, and therefore mutilated, parts. Indeed it may be doubted, whether, in the agglomerated state of the segments, their outline do definitely exist on all their aspects; and whether it be not rather essentially incomplete, through their adhesion to one another. If, however, as appears evident from their refractive powers, the segments are more solid than the medium which connects them, and if they are rounded, and not rectangular, in form, which, after examination with the best instruments, is still confessedly uncertain, interstices must exist, capable, perhaps, of facilitating the motions occurring between these parts.

mencement of my inquiry, are here selected for illustration. Most have their source in a mere derangement of the fibrillæ, whereby the striæ are more or less distorted, or broken. Gradations of these may be seen in fig. 38, and require no comment. They have been described by more than one author. The usual appearance of the striæ in a dissected state, may be best illustrated by a specimen from the heart of an Ox, partially affected by maceration (fig. 17.). The striæ correspond in number with the beads, and the light and dark spaces of the one form those of the other. But there may be a remarkable obliquity of the striæ, as in the new-born Rabbit (fig. 10.) and the Chameleon (fig. 14.), and as may very often be seen in the boiled muscle of the Crab and Lobster. I have observed that in some atrophied muscles, the striæ are very oblique and often bent at a very acute angle in their course, probably from shrinking of the fasciculi (fig. 28.). It occasionally happens that in some fasciculi, or parts of fasciculi, of perfectly healthy muscle, the striæ are precisely doubled or tripled for a certain space, or at the same spot in different states of the focus. The general appearance met with is represented in fig. 19, from the neck of the Duck. In other specimens, where the striæ have been unusually broad, and also thus multiplied in particular parts, I have found it to depend on the segments being regularly aggregated into sets of two or three, some of which showed no interval between their component parts, while others did so. This has been nowhere so well marked as in the Crab (fig. 18.)*. Another unusual appearance of the striæ is displayed in fig. 20, from the Staghorn Beetle.

It seems to have been formerly the universal opinion that the transverse striæ are in all muscles separated by equal intervals. Mr. SKEY, however, has observed that they vary much in thickness and in number on contiguous fasciculi, and he has once seen them varying in size on the same fasciculus. Dr. SCHWANN has also remarked, that they vary in closeness on neighbouring fasciculi. This important circumstance will receive elucidation in the concluding pages of this communication, where the muscular motions will be treated of. At present it is only necessary to detail my observations as to the great variety in the number of the striæ seen on fasciculi within a certain space. The muscle of adult animals, which has been examined after all contractility had ceased, will be alone alluded to. Some specimens preserved in spirit will be included, because I have ascertained, by direct experiment, that, when irritability has ceased, immersion in alcohol does not modify the size or proximity of the striæ.

* A doubling of the number of the transverse striæ may often be seen to be occasioned by an elongation of the interval between the segments, as seen in fig. 15; and I am induced to believe that in other cases an analogous appearance may depend on a progressing development of new segments, by an imperfect fission.

TABLE, showing the variety in the proximity of the striæ in dead muscle. The figures indicate the number of striæ in $\frac{1}{1000}$ English inch.

Number of observations recorded.	Maximum.	Minimum.	Mean.	Greatest difference in same specimen.		
					Min.	Max.
HUMAN .. 27	15·0	6·0	9·4	Sterno-hyoid.....	7·5	12·75
				Sp. constrict. pharyng.	6·75	11·25
				Œsophagus	6·75	11·25
				Cremaster	9·0	15·0
				Rectus cruris	6·0	9·0
MAMMALIA 15	15·0	6·7	10·9	Diaphragm, Cat	7·5	15·0
				Rect. oculi, Horse	9·0	13·5
BIRDS ... 7	14·0	7·0	10·4	Hen (<i>Gallus domesticus</i> , female) ..	7·0	11·0
REPTILES.. 7	20·0	6·7	11·5	Lizard	9·0	20·0
FISH 20	18·0	7·5	11·1	Skate (<i>Raja Batus</i>)	9·0	18·0
				Flying Fish (<i>Exocoetus volitans</i>) ..	9·0	15·0
INSECTS .. 8	16·0	4·5	9·5	Blue Bottle Fly (<i>Musca vomitoria</i>)	5·25	15·0

Perhaps the most interesting conclusion deducible from the above Table, is the uniformity of the mean number of striæ in a given space in the six divisions included in it. The next remarkable fact is, that in each division a great variety is observable in their number, not only in an average of all the examples examined, but in single specimens. And I may add, that this variety has been observed continually, both on contiguous fasciculi, and on the same fasciculus in different parts. I have not considered it requisite to detail the particulars of each observation.

Of the Sarcolemma, or Tunic of the Primitive Fasciculus.

I now proceed to give some account of a structure entering into the composition of all voluntary muscle, and which, though some imperfect notices of its existence are to be found in two or three authors, is not generally known, and has certainly never been demonstrated in that complete and definite manner which its importance seems to demand. I allude to a tubular membranaceous sheath of the most exquisite delicacy, investing every fasciculus from end to end, and isolating its fibrille from all the surrounding structures. It is true that numerous writers have described a sheath to the primitive fasciculus; but that by this term is merely intended a production of that general sheath of filamentous tissue which invests the whole muscle and its lacerti, might be shown by a crowd of quotations*. Other sheaths are indeed mentioned, such as that of MANDL†, said to contain the striæ, and to be

* For example, LEEUWENHOEK, *passim*. PROCHASKA, De Carne Musculari, sect. i. cap. iii. HILDEBRANDT, Anatomie des Menschen von E. H. WEBER, Band i. p. 388. BLAINVILLE, Cours de Physiologie, vol. ii. 1833, p. 311-14. CAUVEILLIER, Anat. Descriptive, tom. ii. p. 14. MAYO, Physiology, 3rd edit. p. 81.

† Traité Pratique du Microscope, p. 75.

composed of a coil of filamentous tissue; but such a structure is entirely imaginary. Mr. SKEY also speaks of the "tube of the fibre," but without any reference to the true sheath*. MÜLLER alludes to it, however, in the following terms. "Each primitive fasciculus has a very delicate sheath, which can often be perceived, forming a transparent border to the fasciculus†." And I have lately met with a passage from an unpublished letter by M. TURPIN, quoted by MANDL‡, in which the author describes it as "a membranous aponeurotic tube, of extreme thinness, white, transparent, and finely puckered or folded crosswise, these folds being rigorously comparable to those, likewise transverse, which exist on the surface of the skin of leeches, when contracted." These folds are afterwards said to be removed by immersion for some days in water, as those of a piece of finely plaited linen would be. From which it seems probable, that the author considers this sheath to be concerned in the production of the transverse striæ. The illustrative sketch confirms this, for the striæ are not seen except where the sheath holds together the primitive filaments, and these are not represented as beaded, where they project as a brush from the extremity§. It will be immediately perceived that the true structure about to be described has no analogy whatever with the cellular membrane of muscle, and that it is not in any way concerned in the production of the transverse striæ; but that, on the contrary, it seems to be a texture *sui generis*, fulfilling a distinct function, peculiar to muscle. It seems advisable, therefore, to call it by a distinct name, and I have been in the habit of styling it *Sarcolemma*||, a term descriptive of its nature. As, however, in what follows, no allusion whatever is intended to be made to the cellular sheath of muscle, the word sheath, to avoid repetition, will be employed as synonymous with sarcolemma¶.

* Philosophical Transactions, 1837, p. 377.

† Physiology, translated by BALY, p. 882.

‡ Read before the Academy of Sciences, December 12, 1831.

§ [Since this paper was read, my attention has been directed to a passage in the 4th edition of Dr. JONES QUAIN'S Elements of Anatomy, 1837, (p. 104-5,) where the author speaks of a "Myolema" as having been observed by himself. The following short extracts comprise all that is said by him concerning it. "The fibre (primitive fasciculus) is not homogeneous or gelatinous, but consists of a tube, the myolema, filled with minute globules, as represented in fig. 26." And a little before, speaking of the "minute extremely close transverse bars" (transverse striæ), "these appear to be in the myolema, and to be owing to its being thrown into plicæ, as they disappear if the fibre is stretched." And again, in p. 81, where a "speculation as to the mechanism of muscular contraction" is offered, "we can hardly suppose it (the nervous influence) to act on the myolema, which is but a delicate or slightly modified cellular tissue." Mr. W. J. E. WILSON¹, who prepared the specimens examined by Dr. QUAIN, also describes the sheath of the primitive fasciculi as consisting of cellular membrane.]

|| This term (from *σαρξ*, *caro*, and *λεμμα*, *cortex*) seems preferable to that of *myolema*, derived from *μύς*, the whole organ, *musculus*.

¶ [While these pages are going through the press, I learn that Professor SCHWANN, in his recent work (Mikroskopische Untersuchungen über die Uebereinstimmung in der Struktur u. dem Wachsthum der Thiere

¹ The Anatomist's Vade Mecum, published in the present year.

This structure can usually be seen best in specimens prepared when recent, but I have preparations which show it perfectly preserved in parts long steeped in spirit. From its extreme tenuity, it would hardly be likely to attract any attention, were it not that, without extraordinary care, it is apt to be detached in different ways from the bundle invested by it, and so to become an isolated object. But when its existence is known, it may often be discovered in unbroken fasciculi, as observed by MÜLLER, under the form of a straight linear margin, uninterrupted, and independent of the striæ; which, however, will very probably seem at first to pass completely across, though they terminate, in fact, within this edge. Some accurate observers have doubted the prominence of the beads of the fibrillæ, because they have been unable to see their bulge at the extreme edge of the fasciculus, a circumstance which may depend on the existence of this sheath.

It may also be frequently seen encircling the areas of fasciculi in the transverse sections of dried muscle (fig. 7. a.), but the readiest and most satisfactory manner of demonstrating it, is to take the fresh muscle of a fish or reptile, and by seizing single fasciculi by one of their extremities, to pull them from the mass. In this operation they undergo considerable stretching, and often break entirely across. But such fractures will vary in extent, and so display the *sarcolemma*, for this is more extensible than the fibrillæ inclosed in it, and therefore, where these have given way, it often remains entire, investing both fragments, and connecting them together. In such a case the severed extremities of the fibrillæ have been pulled asunder within the sheath, and a tubular portion of it, containing a little of the water in which the specimen is placed, extends from one to the other (figs. 32 to 36.). The sides of this, as might be anticipated, are not in focus at the same time, but they have a tendency to fall together, and do so more or less according to their length, and the amount of extension continued to be applied to the fasciculus. The extremities of the tube always pass to the margins of the fasciculus at its broken part, and embrace it, becoming continuous with its transparent edges, already spoken of. If one of the fragments be turned or twisted, the parietes of the tube are twisted likewise, and thrown into wrinkles, which are most readily visible under the microscope, and evince the wonderful tenuity as well as firmness of the tissue. It not unfrequently happens that the fasciculus has given way at several points, and yet its sheath escaped untorn; the consequence of which is that the broken fragments, more or less deranged according to their size, lie in disorder and turned in various directions within the sheath, which still serves to keep them together, and may be discerned stretching from piece to piece, inclosing and embracing them all (fig. 36.). These tubular bridges are sometimes more than six

u. Pflanzen, p. 165.), speaking of the development of voluntary muscle, describes, with considerable accuracy, the membrane here spoken of; and to him its discovery is really due, which I am glad to have an opportunity of acknowledging. He has seen it forming a transparent border to the fasciculi, as well as connecting detached fragments of them, but in Insects and Fish only (see his Plate IV. figs. 4, 5.), and he ingeniously supposes it to be a persistent portion of the membrane of the original cells of development, united to form a single tube.]

times longer than the diameter of the fasciculus, a circumstance which abundantly evidences the strength and tenacity of this extremely delicate membrane. But other fractures will be much more partial, scarcely extending through more than a quarter or a half of the fasciculus; in the gap thus formed, the untorn sheath will be evident by its margin, which has the appearance of being suspended from point to point, and can be traced along the border of the fasciculus. If only two contiguous striæ be separated by the traction, the same thing is observable. These appearances are represented in figs. 29. 30. In fig. 31. is a fasciculus partially withdrawn from its sheath.

It has been already shown that the mutual adhesion of the fibrillæ is liable to vary in amount, sometimes to be almost wanting, and generally to be capable of being diminished by maceration. This circumstance affords a condition to prove the existence of the *sarcolemma*; for as long as that is entire the fibrillæ are kept together, though but very loosely united, and merely fall asunder at the broken extremity, where alone they have space to do so. Thus the brush or tassel is formed, which is described and delineated by more than one writer, and which by showing the striæ of the same size as the beads of the fibrillæ, and here and there passing gradually unto them, convinced FONTANA*, and afterwards SCHWANN†, of their true composition. Sometimes, by accidental violence, a recent fasciculus may be reduced to a pulpy mass, in which fragments retaining their striæ are strewn in confusion, while the sheath may remain uninjured, and preserve all these parts from falling asunder (figs. 37. 38.).

But there is another method by which the existence and some of the properties of the *sarcolemma* may be demonstrated. This depends on the fact that its contents swell considerably when subjected to the action of several fluids, especially acids and alkalies. Phosphoric, tartaric and citric acids, and potash, are what I have employed most commonly. The sheath dilates at first, but soon grows tense; the effect of which on the fibrillæ is, that they emerge at its open extremity, where the fasciculus has been broken off, and there swell in diameter; or if their union is but slight, expand in all directions into a roundish mass or button. Occasionally, in thus emerging, they curl back upon itself the rim of the *sarcolemma*, which then is seen to grasp them still more tightly (see fig. 47. a. u.). But if this vent be insufficient, and especially if the fragment be long, so that its ends cannot be reached soon enough, the over-distended membrane gives way, bursting at detached points, and allowing the escape of the contents. The herniæ thus formed (figs. 39. 40.) admit of easy and close scrutiny by the microscope. They are very peculiar, and curiously illustrate the account I have given of the internal structure of the fasciculus. The fibrillæ are not broken, but protrude sideways in loops more or less decided. Nor is the adhesion by which they are mutually held together dissolved; although, as all are not alike distorted from their true position, it is so far disturbed, that the striæ no longer possess their usual characteristics. The segments of the protruded fibrillæ ceasing

* Sur le Venin de la Vipère, p. 229.

† MÜLLER'S Physiology by BALY, p. 880.

to form transverse lines, are yet deranged with so much regularity of gradation, that other series of lines are produced, of very beautiful curvatures, not unlike, in general characters, the appearance of engine-turned chasing, though less uniform, and undergoing the most varied changes with every alteration of the focus. These elegant curves are seen all through the protruding mass, and clearly demonstrate the manner in which the true striæ are composed. The mode in which the *sarcolemma* gives way is worthy of particular attention. The rupture having taken place, does not extend in any one direction more readily than in another, but only enlarges so much as to give a bare passage to such fibrillæ as force their escape, and generally remains so small as considerably to constrict the base of the hernia. The herniæ are usually, therefore, several in number, each consisting only of a few fibrillæ, and the opening in the sheath assumes a round or oval figure. From this circumstance, no small degree of toughness may be attributed to the *sarcolemma*. So extreme is the thinness and transparency of this membrane, that it is difficult to form any decided opinion as to its structure; but it would seem not improbably to consist of a very close and intricate interweaving of threads, far too minute for separate recognition. Having at least sometimes discerned in it an appearance not unlike what would result from such a texture, I am induced to conjecture so, but the matter is very doubtful. Its external surface seems to be quite smooth and free, being in contact with the capillary and cellular network of the organ, which embraces each fasciculus, in more or less profusion, according to the animal, and the particular muscle. I have never as yet seen any appearance which could give countenance to the opinion that either nerves or vessels penetrate among the fibrillæ, and I am induced to believe that no capillary vessel ever perforates the *sarcolemma*, which seems to constitute an effectual barrier between the parts within and those without. The inner surface of the *sarcolemma* often presents irregularities, as if some attachment of the fibrillæ to it had existed; but it never bears upon it the smallest mark of the transverse striæ, or of any regular marking, unless, as does occasionally happen, some few fibrillæ, or parts of them, remain adherent to it. But this very rarely happens, the whole of the fibrillæ usually evincing a greater facility of separation from the sheath than from one another. A few are seen thus adhering in fig. 75. a.

The inner surface of the *sarcolemma*, however, is naturally adherent to the outermost fibrillæ, and most probably in a particular manner*. From some appearances frequently presented by the fasciculi of insects at their margins, and of which an example is given in fig. 70. a, it would appear that this adhesion takes place to the most prominent parts of the fibrillæ, or, in other words, to the rims of the transverse discs which result from their union. The outer scalloped line in similar cases has no doubt been often mistaken for the outer margin of the fibrillæ. It is, in fact, indicative of the bulging *sarcolemma*, which is bound down to the prominent extremities of the

* [SCHWANN seems to regard the sheath as unadherent to the proper muscular tissue (Untersuchungen, p. 166.), an opinion which the following considerations show to be erroneous.]

light striæ, between which the real margin of the fibrillæ recedes from it, with an intervening fluid. Now in this specimen the interior of the fasciculus is in focus; a central row of *corpuscles* is there seen, and the view of the margin thus represented is, in fact, such as would be obtained by a horizontal section. This fasciculus is thus proved to present on its surface a series of transverse grooves, to which the sheath does not adhere, and in which a fluid is collected. It seems doubtful whether the attachment of the *sarcolemma* to the prominence of the successive discs be so complete as to isolate the intervening grooves from one another.

Another evidence of this adhesion is the following: when the herniæ are formed as above mentioned, it is of course so far destroyed. Now, the intumescence is occasionally so great, that the *sarcolemma* is rent extensively on all sides, and fragments of it only remain, not embracing the whole fasciculus. Wherever the fibrillæ have detached themselves from the sheath they bulge freely, but where they continue to adhere to its remnants, they are confined and constricted, and the striæ cannot expand (fig. 46.). This adhesion will afford an explanation of an appearance that for some time puzzled me. It is described by Mr. SKEV in the following terms: "A fibre (primitive fasciculus) is frequently elongated to a point, up to the extreme external surface of which the circular striæ are apparent. If the fibre be a solid cylinder," he then asks, "What becomes of the central substance? for it is evidently the external surface that is so attenuated, indicated by the presence of the circular striæ*." This kind of fracture, which in Mammalia not unfrequently occurs during the manipulation, is occasioned, I suppose, by traction on the opposite ends of the fasciculus. The superficial fibrillæ do not break so soon as the central ones, because they are supported by the *sarcolemma*, which has been already shown to be the more extensible structure: this stretches them, and when at length they give way, they are much attenuated, fall together over those in the centre, and come to a rude point. From the same cause the extremity of a broken fasciculus sometimes may present an appearance of a tube. What much corroborates this explanation is, that in such cases the terminal striæ are always much widened and distorted.

If the fasciculi be placed in water, some of this fluid is absorbed by them, and they undergo an increase in bulk. This may explain why so many authors have differed from the accurate LEEUWENHOK and PROCHASKA, and asserted them to be of a cylindrical form, for when thus swollen they lose much of that angular shape, which is so convenient and necessary for close package in the natural condition. I allude to this fact, however, for the purpose of introducing a description of one of the most instructive phenomena connected with this investigation. It regards muscle, not in a passive, but an active state; and besides exhibiting the condition of the fibrillæ during contraction, which for the present I omit noticing, furnishes a further proof of those qualities and relations of the *sarcolemma* that have been ascribed to it above. It occurs in fasciculi just taken from the animal, either still living or a moment dead,

* Philosophical Transactions, 1837, p. 378.

and it is in the Frog and Newt that I have found it to be most conveniently witnessed. A few fasciculi laid on glass are separated by needles, wetted, and covered with mica. They are then ready for inspection with a high power. Water is taken up into their structure, and their irritability being still retained, and perhaps excited by the distension of the water, the fibrillæ begin to contract. By the contraction the water is pressed out forcibly from among them, and their mass diminishes in bulk; the fluid at the same time accumulating at their surface between them and the *sarcolemma*. The membrane is thus bulged and torn up more or less extensively from its connections with the fibrillæ (figs. 47. *b.* and 71 to 79.). The process may be frequently watched in its whole course; the contraction of the fibrillæ is the first step, and as this proceeds the sheath is seen to be elevated a little from their surface, at first in small sudamina-like vesicles. By degrees these increase and coalesce with more or less facility, sometimes subsiding in one part to rise larger in a contiguous one. These slighter and earlier stages of the phenomenon are best seen at the margin of the fasciculus, where a profile view is obtained; but when the changes are more decided, or indeed even when they are but trivial, provided the eye is prepared to detect them, they may be discovered on the surface next the observer: and generally, the folds of the *sarcolemma* occasioned by a large bulla visible at the margin are traceable for some distance over the proximal surface. In such a case the fibrillæ and their striæ are beyond the range of the focus in which the *sarcolemma* is apparent. Sometimes the fluid is expressed in such quantity, as to separate the tunic completely from the fibrillæ for some length, a circumstance which becomes especially notable when the specimen is accidentally bent, for the fibrillæ then take the shortest course along its concavity, the distended membrane forming the convexity of the curve at a considerable distance. The whole *sarcolemma* thus assumes the appearance of a crystal tube, filled with a transparent fluid, immersed in which the fibrillæ pursue their course as a contracted bundle.

Lest it should be imagined that the fluid forming these bullæ is a normal constituent of the fasciculi, I may observe that none are developed on contracting muscle, when either unwetted, or immersed in a medium of some density, as syrup. Bullæ already formed are immediately removed by the presence of syrup, which absorbs their water, and yet I have sought in vain in uncontracted fasciculi placed in syrup for any appearances of shrinking, which would necessarily present themselves did a fluid of so little density exist naturally among any interstices of the fasciculi.

There is another illustration of the existence and qualities of the *sarcolemma*, which seems of so novel and interesting a character, that I cannot refrain from mentioning it. In an Eel, which to all appearance was in perfect health, and contained as usual among its muscles, a considerable quantity of fat, one fasciculus of the same size as the rest, instead of presenting the muscular substance, was reduced to a mere diaphanous tube, containing a number of minute parasitic worms, coiled up like the *Trichina spiralis*, and closely packed together (figs. 41 to 45.). The *sarcolemma* was

quite entire, and seemed without disease, but no trace of fibrillæ could be discerned on the closest examination. In fact, the sheath of the fasciculus was the only part remaining, the rest having probably become the food of these entozoa. As both ends of the tube remained open, having been broken off, several of the worms escaped from their confinement, and began to show signs of life, uncoiling themselves, and moving about slightly in different directions, with an undulating motion (fig. 42.). They were about $\frac{1}{8}$ th of an inch in length, blunt at one end, and tapering considerably towards the other. They contained in their interior numerous detached dots or granules, of different sizes, but without the appearance of complicated structure, and there were no orifices detectable on their surface (figs. 42. 43.). Among the extruded worms there were many globular or oval bodies, nearly as large as one of the coiled parasites, and marked like them with minute dots. Some of these were evidently worms very compactly coiled, but in others no coils could be distinguished. These were smaller, invested by a very delicate membrane or cyst, having the appearance of immature animals (figs. 44. 45.). The whole number of worms in the sheath, I found to be more than 100. No other fasciculus was discovered in this state, but owing to want of time, a strict search was not made. Having previously examined minutely several recent examples of the *Trichina spiralis*, the well-known microscopic entozoon of voluntary muscle, the analogy in form, size and situation, between that and the one now described, at once struck me; but the following points of difference will be immediately perceived. The *Trichina spiralis* lies in the cellular membrane among the fasciculi, always external to the *sarcolemma*, occupying a cell formed around it by the vital actions of the creature which it infests. Moreover, it is always solitary. On the other hand, this *internal Trichina* being within the *sarcolemma*, is entirely unconnected with vascular or cellular parts, is not confined by a cyst, but by the unaltered sheath, and it is gregarious. No artificial method of preparation could more convincingly have proved the toughness and comparative indestructibility of the *sarcolemma*, than this remarkable morbid condition, accidentally met with.

I have ascertained the existence of the *sarcolemma* in Insects, Crustacea, Fish, Reptiles, Birds and Mammalia, and have so seldom failed to demonstrate it at pleasure in any of these classes, that I assume it to be an essential part of the composition of the fasciculi in all animals belonging to them. In some, it is more readily made apparent than in others, and by different methods of procedure, but by one or all of the modes of demonstration above enumerated, there is abundant evidence of its existence in all. The elevation of it by water, pressed out during contraction, may be witnessed in all these classes without exception. In the human subject, the *sarcolemma* is formed as early as the period of birth (fig. 30.). The striæ are then strongly marked, and the fasciculi are in such a state of development as to be capable of performing motions of considerable extent. From this early epoch I have traced this structure at various ages, and in both sexes, to old age, when the atrophy of the muscles has often seemed to render it more easy of detection. It also remains in muscles wasted by disease or

inactivity at other periods of life, and no difference has appeared to occur in it, whether the specimens examined were flaccid or firm, pale or dark-coloured. In Birds, an exceedingly delicate *sarcolemma* may be occasionally seen connecting the broken ends of a fasciculus, but it is rare to discern any contraction under the microscope in fasciculi inspected even instantly after death, so quickly does their irritability cease; and where vesicles are discovered, they are small and transparent, and would be apt to pass unnoticed unless specially sought for. What may be connected with this circumstance is, that the fibrillæ show a great proneness to fall asunder in this class, their adhesion to one another being but slight; the transverse striæ are often much deranged by dark irregular longitudinal streaks, and in a transverse section, as already seen, the fibrillæ are shown more isolated and distinct than in any other examples. In Insects, I have repeatedly seen the *sarcolemma* raised from the surface of the fibrillæ, where they were undergoing contraction (figs. 71 to 74.).

With regard to the *use* which this remarkable structure may be intended to serve in the economy of the organ, our present ignorance of the essential cause of motion renders any explanation that might be offered, of doubtful value. But it has appeared probable to me, 1st, That it may act as a mechanical protector and isolator of the contractile tissue inclosed within it; 2ndly, That its exquisitely smooth external surface may facilitate those rapid minute motions of neighbouring fasciculi one against another, which will afterwards be shown to occur, in all likelihood, in contracting muscle; and 3rdly, That, from its apparent similarity in structure to the membrane of the nervous tubules, which run among the fasciculi, and between which and the proper contractile tissue it seems certainly to intervene, as well as from its extensive contact and union with the surface of the latter, it may be the conducting medium of that influence, whose mode of propagation the late discoveries of the loop-like termination of the nerves of muscle, have hitherto only seemed to render more inexplicable than ever.

Of the Corpuscles of the Primitive Fasciculi.

There is a fact in the anatomical history of voluntary muscle which, from its apparent universality, is entitled to some attention, and yet which seems hitherto to have escaped the notice of anatomists; this is, The existence in the primitive fasciculi of minute bodies of a definite form and structure, generally invisible, unless rendered evident by special modes of preparation. The most ready method of demonstrating them, is to touch the specimen with a small quantity of one of the milder acids, as the citric. These agents cause an instantaneous tumescence and transparency of the fasciculi, as has already been stated, and the corpuscles become at once clearly defined. But by the swelling of the fibrillæ among which they are situated, they may be seen to undergo some distortion from their real shape, and it is generally in certain parts alone, as where fibrillæ have escaped from the *sarcolemma*, or the corpuscles become detached, that they present their natural characters. They then appear to be

oval or circular discs, frequently concave on one or both surfaces, and containing somewhere near the centre, one, two, or three very minute dots or granules (figs. 39. a. 40. a. 51. a., &c.). This at least has been their most common form, when they have seemed most entire and free from injury. It is also their general shape when discernible, as occasionally happens, without chemical treatment. But they present some varieties in figure, being sometimes thick or elongated, or curved and irregularly oblong, at others of indefinite shape and granulated aspect. It is doubtful, however, how far those having such characters are modified by the circumstances of the examination. I have witnessed the breaking down of the more regular ones into a granulated mass, in repeated instances, on the addition of acid, by the forced elongation of the fibrillæ, among which they lie (figs. 39. 47.), and am therefore induced to think such specimens to be generally misrepresentations of nature. If they be not always fallacious, they may be regarded as an indication of a deposit and absorption of successive crops of corpuscles. These bodies are usually numerous in proportion to the size of the fasciculus, so that as a general rule equal masses have about equal numbers; but this is liable to some exceptions, as the same fasciculus may sometimes have them crowded in one part and more scanty in another. Where the fasciculus is small, as in Birds and Mammalia, they lie at or near its surface, but in contact with the fibrillæ, within the sarcolemma. This is clearly shown by bringing into focus different portions of the fasciculus in succession, under high powers, as well as by a corpuscle occasionally adhering to the sarcolemma when separated by fluid from the surface of the fibrillæ. But in proportion as the fasciculi assume a greater bulk, the corpuscles are found to be diffused more uniformly through their substance, and may be everywhere traced by a moving focus. This is especially the case in Reptiles and Fish, in which I first met with them, and where they are at all times the most convenient for observation*. In the Insects that could be most readily obtained, and which have been submitted to examination, they are usually disposed with more symmetry, either singly or in pairs, along the central axis of the fasciculus (figs. 53. 54. 70. 73.), an arrangement occasionally observable in Reptiles (fig. 46.), and which affords an important insight into their essential nature. In one instance (in the Chrysalis of the Tiger Moth, fig. 55.) a number of corpuscles similar to these were observed on the exterior of a fasciculus, but their relations are doubtful. These corpuscles have manifestly some adhesion to the fibrillæ with which they are in contact, since they are influenced by their movements (figs. 39. 47. 85.), and generally retain their connexion with them, when these are torn asunder from one another (fig. 49.). Some, however, often become detached, and float in the fluid by which the object is surrounded, thereby evincing their existence as independent parts. They lie among the fibrillæ, but so attenuated is their form, that they do not derange the striæ. Sometimes, indeed, a dark longitudinal streak may be observed, extending on either hand from

* Their dispersion among the mass of fibrillæ is well seen in a transverse section from the Skate (fig. 3.), but in general they are not thus visible.

the position of one of them; and nothing is more probable than that where such an appearance is not due to violence in manipulation, it may have led to the error of supposing the fasciculi to be compounded of smaller bundles of fibrillæ, as MUYS regarded it, or of strands, or flattened sets of them, according to the views of a later writer*. It is owing to their extreme tenuity, and the interfering presence of the transverse striæ, that in the ordinary state, the corpuscles are concealed, and it is by the augmented transparency of the fasciculi, and the more or less complete removal of the striæ, that they are so easily brought into view by acids. And yet there is in this some other principle at work; for brine and the alkalies weaken the striæ and remove the opacity of the fasciculi, sometimes without materially serving to display the corpuscles. Figs. 48. 49. are taken from a specimen which has been kept some time in spirit, and which when first immersed did not display a single corpuscle. This fluid has not only rendered them more opaque, but has imparted to them a brown colour. In general, however, muscle that has been kept long in alcohol, shows no corpuscles.

It is now well known through the researches of VALENTIN and SCHWANN, that the fasciculi of voluntary muscle, in the earliest stage of their development, consist of a series of nucleated cells, and that the nuclei continue visible during the period of foetal growth, while those changes are in progress, that terminate in the formation of the transverse striæ. They have been supposed to be then absorbed, and it is certain that they do disappear, but I have found that they are only obscured by the growing striæ that surround them, and that they are capable of being rendered evident by the same means which have been already shown to discover the corpuscles in the adult. These nuclei of the sarcogenic cells present the identical characters of the corpuscles of adult muscle, and that they are both the same structure, may be regarded as proved by their being met with at every intervening period without any intermission. In confirmation of this view, it is worthy of remark, that the arrangement of the corpuscles in the adult corresponds with their particular variety of disposition in the developing muscle of the same animal. In the larvæ of several insects, in which both perfect and imperfect fasciculi may be examined at the same time, the row of central corpuscles is equally well marked in both when properly prepared.

In an early stage of their development, the primitive fasciculi are often narrow flattened bands, and present bulgings at irregular distances, which depend on the existence of these bodies. It is interesting to notice how closely, in this state, they resemble in form, size, and structure, the adult condition of the muscle of organic life, which has for the first time been correctly represented and described, though in brief terms, by Dr. BALY, the able translator of MÜLLER's Physiology. This is a fact which may hereafter prove important in the history of organic development. The similitude may be seen by a reference to figs. 56. 60. 66, where both kinds of fibre are delineated. The corpuscles of organic muscle are brought much more com-

* SKRY, Philosophical Transactions, 1837, p. 374.

pletely into view by treatment with acid (figs. 65. 67.). In conclusion, it may be observed, that in the course of my investigations into the minute structure of organs, I have noticed corpuscles of a similar character in the *sarcolemma* itself, in the coats of capillary blood-vessels, in the sheath of nerve, and in the substance of tendon, all of which I believe to be analogous, both in their origin and nature, with those now described; that is, they are the nuclei of cells from which these several structures have been originally developed. It is, however, not impossible, that in all these cases, there may be during development, and subsequently, a further and successive deposit of corpuscles, from which both growth and nutrition may take their source. In the case of muscle, indeed, this may be regarded as certain, since their absolute number is far greater in the adult than in the foetus, while their number, relatively to the bulk of the fasciculi, at these two epochs, remains nearly the same.

Of the Extremities of the Primitive Fasciculi, and their union to other Structures.

This has always been a subject of considerable interest, and an examination of it is necessary to complete the idea of a primitive fasciculus. I presume it to be well understood, that all fasciculi of voluntary muscle are fixed immediately to some tissue analogous to the fibrous. Such at least is the case in the higher classes, and in the lower it is probably universally true. The gross form under which this fibrous tissue is arranged, it is not my purpose to speak of, as nothing more is here intended than to inquire how the minute fibrils are disposed at their attachment to the fasciculi, and how these fasciculi terminate. The observations which follow are few in number, and it must be left for the future to determine how far the facts elicited are of general application.

In Mammalia and Birds, it will always be found a very difficult task to detach from the mass a small set of tendinous fibrillæ, with the primitive fasciculi belonging to them, in such a way as to gain an unequivocal view of their union; and all my attempts to do this have hitherto failed. This result is to be attributed to the smallness of the fasciculi, and to the abundance and intricacy of the cellulo-vascular net-work by which they are commonly surrounded, these circumstances tending to prevent the disengagement of the individual fasciculi, and therefore of the minute detachment of tendinous fibrillæ with which each is furnished. In Fish, neither of these obstacles occurs, and accordingly in this class the most satisfactory evidence on the subject is to be found. So many deceptive appearances are apt to present themselves in an investigation of this nature, that no conclusion can be fairly drawn from any fasciculus not entirely isolated; for it is impossible correctly to appreciate the relations of muscular and tendinous parts when mutually intermingled. From inattention to this circumstance, I conceive that excellent physiologist TREVIRANUS has fallen into the error of supposing the fasciculi to taper much towards their extremities, so as to be inserted among, and to be embraced by, the fibrils of the tendon*. In the case of

* Beiträge zur Aufklärung der Erscheinungen und Gesetze des organischen Lebens, von G. R. TREVIRANUS, Tab. VIII. Fig. 59.

Fish, it is only necessary to procure a fragment (as for instance from the Skate), in which the primitive fasciculi arise by tendon. If a minute portion of this tendon be now severed with the muscle attached to it and laid upon glass, it may be split up without difficulty by means of needles into very minute particles. Some of these may be tendon alone, some muscle alone, but others will consist of them both united, and will here and there present accidentally a fasciculus distinct from the rest, with its little bundle of tendinous fibrils attached. Care must be taken not to confound the clear diaphanous *sarcolemma*, which is almost sure to be made apparent in this procedure, and may be wrinkled, with the undulating fibrous tissue. In such specimens the tendinous and muscular structures are readily distinguishable from one another, and the line of demarcation between them is often so definitely in view, that no doubt can be entertained as to the genuineness of the appearances. The tendon seems to transmit a small detachment of its fibrils to each primitive fasciculus, proportioned to its size; which arriving near its extremity, expands towards it, and is immediately lost by direct continuity with it (figs. 68. 69.). The fasciculus does not commence of a taper form, but is of the same bulk at its extremity, as in any other part of its length, and the striæ begin from the very extremity of the fasciculus. That is, all its fibrillæ are of equal length, and terminate on a level. The beads or segments, too, are uniform in number on every fibrilla of the same fasciculus, or, in other words, the terminal disc is a perfect one. The sarcolemma also continues to invest it to its extreme end, and there seems to terminate abruptly. It follows, therefore, that the extremity of a fasciculus, if a direct view of it could be obtained, would present the same parts as a transverse section, viz. the extremities of fibrillæ inclosed by a ring, which would be the terminating margin of the sarcolemma. I believe it to be to all these parts that the tendinous threads proceed and become fixed, for the following reasons:

1st. Such a fasciculus being regarded lengthwise, an uninterrupted clear line is traceable along its edge, and beyond its extremity, where it becomes continuous with the margin of the tendinous bundle.

2nd. The abrupt line of demarcation between the muscle and the tendon is visible throughout, as the focus is made to descend through the object, so that as successive muscular fibrillæ are brought into view with their striæ, successive fibrils of the tendon also appear.

In Crustacea and Insects, in which the muscle is united to hard tendinous or analogous surfaces, the fasciculi terminate unequivocally by a corresponding surface, at the margin of which the *sarcolemma* finds attachment. I have seen this very plainly in certain insects, as the legs of the Water Scorpion (*Nepa cinerea*). But the class of Insects will furnish examples of the clearest kind in direct confirmation of the view already taken of this subject in Fishes, and, therefore, showing with how much propriety we may probably venture to extend the description there given to the higher orders, whose primitive fasciculi have so striking a similitude in every essential particular to the same structure in the lower. In fig. 70. are given the ap-

pearances of two fasciculi out of many similar ones, taken from the leg of a common Blue Bottle Fly (*Musca vomitoria*). These are detached from one another, and each has united to it the small set of tendinous fibrillæ (here stiff, and somewhat horny, but divisible into exceedingly minute threads,) serving to prolong it to its fixed attachment. In these beautifully delicate parts, the following circumstances may be observed. 1st. The tendon expands to fix itself to the extremity of the fasciculus, and there abruptly terminates, the line of union being definitely notable. 2nd. The extremity of the fasciculus being with certainty apparent, has precisely the same appearance as its other parts, presenting a perfect terminal disc, and the sarcolemma attached to its border. The corpuscles also advance as far as the extremity.

On the Mechanism of the Movement of Voluntary Muscle.

Nothing certain is yet known concerning the more minute changes which the primitive fasciculi undergo during a state of contraction. The theory of PRÉVOST and DUMAS, though still finding a place in the best physiological works, seems to be falling every day into more general discredit. Many who have endeavoured to inspect the phenomenon on which it was based, have failed in convincing themselves that it is the true condition of contraction; and others, though noticing the fact of the zigzag flexure of the fasciculi, have not confirmed the account given of the correspondence of the angles to the transit of nerves. Professor OWEN has been led to doubt it "from observing the contraction of the muscular fibres in small filariæ (such as commonly infest the abdominal cavity of the Cod), and more especially from observing the contraction of the retractor muscles of a species of Vesicularia. "Each separate fibre of the retractor muscle," he says, "is seen with great distinctness, and is characterized by a single knot or swelling in the middle. In the act of retracting the tentacles, the fibres become shorter and thicker, especially at the central knot, but do not fall out of the straight line*." I am ignorant whether these be fasciculi having transverse striæ. If not, the bearing of the observation on the contraction of striated muscle is less direct and important. The same acute observer afterwards explains, that the zigzag folding of the fibres is characteristic of their state of relaxation, when not stretched by antagonist muscles. Dr. ALLEN THOMSON also, on repeating the experiment of HALES and PRÉVOST on the Frog, "observed single fibres continuing in contraction, and being simply shortened, and not falling into zigzag plicæ: and he was led to suspect, from this and other circumstances, that the zigzag arrangement was not produced until after the act of contraction had ceased†." M. LAUTH, who seems to have investigated this subject most carefully, states that a fasciculus may shorten with or without gigzag inflexions; but he supposes that at all times the fasciculus presents in its whole extent transverse rugæ, which may probably, he says, be due to the contraction of the primitive fibrillæ‡. MÜLLER says, that contraction by the

* HUNTER'S WORKS, PALMER'S Edition, vol. iv., Note, p. 261-2.

† Ibid.

‡ L'Institut, No. 73, quoted by MÜLLER, BALY'S Translation, p. 888.

approximation of the bead-like enlargement can neither be demonstrated nor proved not to take place, but he seems inclined to think such a conjecture not improbable, because the beads of the fibrillæ are not necessary to the contraction of the fasciculus into belly-like portions, or to their zigzag inflexion; and also because the striæ are not always at the same distance on contiguous fasciculi. "This," he adds, "is all that can be said in support of the hypothesis of the approximation of the globular enlargements of the primitive fibrillæ*."

I was endeavouring eighteen months ago to inspect, under the microscope, a fasciculus of a Frog, excited by galvanism, and had induced contractions in the specimen so often that it seemed no longer to obey the stimulus applied to it. Continuing to regard it, however, I was surprised to perceive a spontaneous and slow movement, which consisted of an approximation of the transverse striæ, with a corresponding shortening and thickening of the fasciculus. What I have now to offer is chiefly embodied in this simple fact, though somewhat amplified by subsequent researches. From these I am enabled to say with confidence, that in that form of contraction which takes place as the last act of vitality, the transverse striæ, that is, the discs of the fasciculus, approach each other, become thinner, and expand in circumference; in other words, the contractility of muscle is independent of any inflexions of its fasciculi, and resides in the individual segments of which these are composed. I have taken from the animal, immediately after death, a minute piece of some muscle, generally of the extremities, and laid it upon glass, then quickly tearing it into many fragments with needles, so as to separate the fasciculi as much as possible from one another, have moistened it with water, and covered it with a lamina of mica: a magnifying power of 300 or 400 diameters has then been employed. In this manner the muscle of animals possessing transverse striæ may be seen in a contracting state. The contraction commences usually at the cut extremities of the fasciculi (fig. 85.), which are thereby rendered more opaque. The striæ are here seen to be two, three, or even four times as numerous as in the intermediate part, and also proportionally narrower and more delicate. As the process goes on, the striæ advance towards those of the contracted portion, and on approaching it are gradually ranged in close apposition to them. The line of demarcation between the contracted and uncontracted portions is well defined, and as fresh striæ are absorbed from the latter into the former, it is seen to make an onward progress. As it advances upon the uncontracted portion, this diminishes rapidly in length, without the contracted part experiencing an equivalent elongation; the consequence of which is a shortening of the whole fasciculus. The contracted part augments in thickness, but in a degree, I think, incommensurate with its diminished length, so that its solid parts actually lie in smaller compass than before; they are brought into closer apposition with one another. The effect of this is, that the water that has been absorbed is pressed out from the fibrillæ, and accumulates, where it is best able to do so, between the fibrillæ

* Physiology, BALY's Translation, p. 889-90.

and sarcolemma, giving rise to the appearances of bullæ already described. It often happens, but not necessarily, that besides the approximation of the striæ, the contracted portion exhibits inflexions at distances, sometimes nearly regular, but generally not so, and including from five to thirty, or forty striæ. These inflexions are very slight, and engage either a part or the whole of the fasciculus. They do not occur even when most regular, at special and determinate situations, but may often be seen to alter their position as contraction proceeds, probably in consequence of its irregularity. These inflexions or rugæ, however, are not peculiar to the contracted part, but are seen not unfrequently in fasciculi, which present no contractile movements, and no unusual proximity of the transverse striæ. The contracted part of the fasciculus may be frequently recognized merely by its greater opacity, and its more evident longitudinal striæ*.

It happens, as might be expected, that these several circumstances are seen under considerable varieties in different animals and modes of observation, but in the main they are very constant and easy of demonstration. In Mammalia, as the Mouse; in several Reptiles, as the Frog, Newt, Adder; in Fish, as the Eel, Skate; and in Crustacea, as the Crab and Lobster; and in Insects, they have been repeatedly witnessed by many gentlemen to whom I have shown them (see Plate XIX.). In the three latter classes, however, they are best seen, and best of all in the Crab and Lobster, for the tardiness with which the irritability of these animals departs, prolongs the period of observation, and renders the stages of the phenomenon more distinguishable from one another. The contraction, besides occurring at the ends of the fasciculi, often begins independently at one or more intermediate points, and can here be observed under peculiarly favourable circumstances, for the muscle is very transparent, though the fasciculi are of extraordinary dimensions.

The first appearance is a spot more opaque than the rest, caused by the approximation of a portion of a few of the discs towards each other; that is, by the shortening and gathering together of a few segments of a limited number of fibrillæ. By altering the focus, the phenomenon may be ascertained to extend as much in depth as in breadth, so that the contracted portion may be compared to a solid ball, lying in the midst of uncontracted and flaccid parts. If this ball be at the surface, the almost invariable concomitant is a collection of expressed water in bullæ between the sarcolemma and fibrillæ. The contractile force seems to be exerted solely in the direction of the length of the fibrillæ, for in this direction only are the striæ beyond the spot distorted. The distortion consists of an extreme stretching and widening of them and their interspaces, which is greatest close to the ball, and gradually ceases at a distance of thirty, forty, or more striæ: thus the fibrillæ not implicated in the contracted ball are undisturbed, while those so implicated have their segments drawn

* Owing to the polygonal, and sometimes flattened form of the fasciculi, they may present, if twisted, an appearance of unequal thickness at different points of their length, without there being, in fact, any contraction, or approximation of the transverse striæ.

closely together in the one part, and stretched to a corresponding degree immediately beyond. This first stage is represented in fig. 89.

The nucleus of contraction slowly extends itself, by involving a greater length and a greater number of fibrillæ, and while doing so, has generally an oscillation along the implicated fibrillæ, effected by the alternate attraction and partial release of striæ at its opposite ends. It would almost appear as if the contractile force of the spot were limited; able only to engage a certain amount of the mass; so that, as fresh portions were assumed on the one hand, some were relinquished on the other. But the occasion of the oscillation would seem to be the traction of neighbouring points, also active, striving to acquire additional striæ; for, as before observed, the cut extremities are always the first to contract, and being thereby rendered thicker, are in some measure restrained from approaching each other by the mica or glass, with which it is necessary to cover the object. Be that as it may, the movements are such as to convey the idea of opposing forces struggling for the mastery, and they do not cease till the whole fasciculus is contracted to less than half its original length. They prove incontestably, that the agency in question, whatever it may be, operates primarily on the individual segments of the fibrillæ.

When a contraction is very forcible and going on at the same moment at several points of a fasciculus, it may happen, if the pressure on the extremities prevents their approximation, that the intermediate flaccid portions are stretched even to laceration, as seen in fig. 75. from the Frog. This fact may serve to illustrate those remarkable cases of muscular rupture from inordinate action, concerning which much has been written*.

In the Skate, the following appearances once presented themselves. Dark waves of contraction, caused by the successive approximation and recession of one side of the discs, began to play backwards and forwards along one margin of the fasciculus. These gradually included the whole breadth of the fasciculus, and then coalesced; permanent rugæ at the same time forming in addition, each about $\frac{1}{40}$ th inch broad, and including twenty or thirty of the approximated striæ. Fig. 88. exhibits these alterations.

A contracted fasciculus has often a somewhat uneven or undulated margin, which is sometimes occasioned by very slight irregularities or puckerings of the fibrillæ, but more frequently by a transverse wrinkling of the sarcolemma, which, when this is extensively separated by fluid from the fibrillæ, is almost a necessary consequence of

* See J. L. PETIT; and M. ROULIN, MAJENDIE'S Journal, vol. i. p. 295. [I have just been indebted to the kindness of Mr. BUSK, surgeon to the Dreadnought Hospital Ship, for an opportunity of examining specimens of muscle, ecchymosed and ruptured by spasmodic action during a rapidly fatal tetanus. We found them to present appearances of disintegration, such as are frequently seen in fasciculi inordinately contracted under the treatment above described, and this to so great an extent, that in many parts neither transverse nor longitudinal striæ could be discerned, but only a confused mass of primitive component particles, held together by the sarcolemma, as seen in a portion of fig. 37. from the Frog. Other muscles from the same subject, which had been free from spasm, were in all respects natural.—November, 1840.]

the shortening of the fasciculus. I have not seen this in contracted fasciculi that have not been wetted, and, therefore, conclude the sheath to be endowed with the requisite elasticity for accommodating it to the varying form of its contents. But where bullæ are developed, the folds thus occasioned are strongly marked, and have very probably been not unfrequently mistaken for transverse rugæ upon the fasciculus. The fibrillæ, however, are entirely independent of them, as may be seen in specimens taken from the Newt (fig. 76.) and Mouse (fig. 80.). In those Birds that have been examined, the irritability has so speedily ceased, that no contraction has been observed.

It is almost unnecessary to remark how completely the variety before noticed in the proximity of the striæ in all animals in contiguous and even the same fasciculi, is illustrated and explained by the foregoing facts.

Such are the principal phenomena observed during that form of contraction which I conceive to be analogous to the *rigor mortis**; but it is undoubtedly necessary to bear in mind, that the fasciculi in which they occur are in a condition very different from those acting in the living body under the influence of volition. It is not by any means intended to be implied, that the healthy movements of muscle are in every respect such as have been now described; but it seems highly probable, that in kind, at least, they are identical with them. Perhaps, therefore, the mechanism of voluntary motion may receive some elucidation from this phenomenon of lingering vitality. A muscle, if cut whilst irritability remains, retracts to a greater or less extent, as is seen every day in amputations; this is by virtue of a tendency, always existing, towards approximation of the discs, for if a piece so cut be immediately examined, the striæ are seen regular in form, and the fasciculi without rugæ. The contraction just now described is a subsequent change; and in it a still further approximation of the striæ is observed, often so great as to diminish the whole length by more than a half, which is more than occurs in living muscle, even during extreme action. Now the consequence of this is not always the production of even any disturbance of the straight direction of the fasciculus, though small rugæ are frequently formed. From this it is evident, that the discs have a very extensive range of motion, quite sufficient to effect, without other mechanism, the ordinary movements of volition.

Now with regard to the existence of the rugæ and zigzags in the living body, there

* It will probably be no longer doubted, that this interesting and much-canvassed phenomenon is to be ascribed to the muscles; and it need hardly be said how close a bearing the observations above detailed will have on the explanation of its physical mechanism. For impartial evidence of the present unsettled state of the question, consult MÜLLER's Physiology, BALY's Translation, p. 890 *et seq.*

It is also evident that these observations prove the property of contractility to be inherent in the very structure of muscle, and to be capable of being called into action without the *immediate* instrumentality of nerves; for the fasciculi submitted to examination, after being entirely isolated from every surrounding structure, and then remaining some time in a state of rest, have frequently exhibited the contractions described, on the addition of water, which seems to act as a stimulus to them, or by the accidental pressure on some point of their surface of any extraneous fragment of dirt that might happen to be present in the field of the microscope.

is a difficulty in comprehending how they can be caused by the approximation of the discs: and to suppose them produced by a different principle, seems at variance with our experience of the simplicity displayed in all the operations of nature. The only way in which it would appear possible for the *rugæ* to be formed through the instrumentality of the discs, is by assuming a partial contraction on alternate sides of the fasciculus, the concavity of the bend having the closest set *striae*; but a force thus expended must act at immense disadvantage, and it will not explain the zigzags, which often include many smaller *rugæ* within them*. Independently of this objection, these flexuosities have been shown by the observations of Professor OWEN, to be characteristic, in *filiaræ*, of the relaxed state of the fasciculi, under the circumstances which bring their two attached extremities nearer each other†. Moreover, in examining the abdominal muscles of the Frog, I have found that, after their irritability has ceased, the zigzag *plicæ* may be very readily produced at pleasure by approximating mechanically the extremities of the fasciculi; and it cannot surely be thought extraordinary, that under such circumstances the zigzags should often be of nearly uniform size, or that the passage of vessels or nerves among the fasciculi should have the effect of determining the flexures to take place at this or that particular point. I have likewise observed the same thing in various muscles examined under the microscope. Hence it is highly probable, that flexures are always the natural position into which fasciculi are thrown, if, on elongation following contraction, they are not at once stretched by antagonist muscles.

But how is it that, in living muscles undergoing contraction, zigzag *plicæ* have been seen to occur? The independent power of action of the individual fasciculi has been already shown; and what is more probable than that, in a contracting muscle, these are not all acting at once, but that some contract while others are relaxed? I laid bare the muscle of a living Rabbit, and took hold of a portion of it with a pair of forceps in such a manner as to maintain a steady moderate pressure on the part. The effect of this was not a continuous contraction of the whole part irritated, but a very rapid succession of jerking contractions, implicating its different fasciculi one after the other, by which a continuous approximation of the ends of all the fasciculi irritated was produced. Now here there were straight and zigzag fasciculi; and it is plain that the straight were the shorter, or the contracted, the zigzag the longer, or relaxed. Indeed, if in any muscle in action, zigzags be observed which are not universal, the fasciculi in which they occur must be in a relaxed state, compared to those having a rectilinear direction, and the phenomena of contraction cannot therefore be legitimately referred to them. If zigzags be requisite for contraction, there ought to be no straight fasciculi interspersed among them, but observation teaches us that there are. Besides, when the abdominal muscle of the Frog is laid on glass for obser-

* In detached fasciculi, indeed, I have sometimes seen this (fig. 81.), but consider it the result of irregular contraction.

† HUNTER'S Works by PALMER, vol. iv. p. 261.

vation, and made to undergo contraction, which, when excited by galvanism, is a momentary act, and difficult of inspection, the return to a straight line, on relaxation, is not brought about by an antagonist force; the ends remain approximated, but the fasciculi being actually elongated fall into zigzags. A phenomenon, the cause of which has frequently been speculated on, may serve yet further to elucidate this hitherto obscure question, I mean that of the sounds heard by applying the ear to a muscle in vigorous action. These sounds have been compared to an exceedingly rapid faint silvery vibration, and they seem to me to be explicable by supposing the several fasciculi to be in rapid and constant motion, one against the other, by varying amounts of contraction in different fasciculi and parts of fasciculi. It has been already shown that a part of a fasciculus may act independently of the rest; that a contraction may oscillate to and fro along a fasciculus, or travel from one end of it towards the other. These phenomena are not imaginary, but may be readily observed by any one in contracting fasciculi removed from the body; and though I do not mean to assert their occurrence in voluntary and healthy contraction, there would appear to be no difficulty in the present state of our knowledge, in concluding that such is actually the normal condition during life.

The chief results of the above inquiry may be thus briefly recapitulated:

1. The *primitive fasciculi* of voluntary muscle consist of elongated polygonal masses of *primitive component particles*, or *sarcous elements*, arranged and united together endways and sideways, so as to constitute in these directions respectively, *fibrillæ* and *discs*, either of which may, in certain cases, be detached as such, and both of which, in the unmutilated organ, always exist together. It is the assemblage of these particles, which may most properly be styled "Sarcous tissue."

The dark longitudinal striæ are shadows between fibrillæ, the dark transverse striæ, shadows between discs.

2. Every primitive fasciculus is invested by a highly delicate, transparent, and probably elastic membrane, the *sarcolemma*, which is adherent to its surface, and isolates the sarcous tissue from every other part.

3. Every primitive fasciculus contains upon or among its primitive particles, numbers of *corpuscles*, which either actually are, or are analogous to, the nuclei of the original cells of development; and it is certain, that during growth, these corpuscles increase in number.

4. The *extremities* of the primitive fasciculi, in certain cases at least, are directly continuous with tendinous structure, and are not taper, but obliquely or transversely truncated. This is at variance with the common opinion that the tendon embraces each fasciculus, and is continued along it from end to end, constituting its cellular sheath.

5. In *contraction* of the fasciculi, observed *after death*, the primitive particles are

approximated and flattened in the direction of the length of the fasciculi, and expanded in their transverse direction.

6. Such *contraction* may engage a few such particles only, or the whole fasciculus, may oscillate from end to end, without occurring at any special situations or intervals, and may be independent of immediate nervous co-operation.

7. *Rugæ* and *zigzag inflexions* are a mere consequence of the approximation of the extremities of a fasciculus, otherwise than by its own contraction, and are necessarily obliterated by either its own contraction, or its elongation by other forces.

8. It is highly probable, that in all *contractions* of voluntary muscle in the *living body*, the same mechanism is employed as in the dying; and that in the living body, these contractions engage only parts of fasciculi at a time, and oscillate along them, as well as occur alternately in different sets of fasciculi.

9. These results are true as regards the *vertebrate* and *articulate* classes of the animal kingdom.

I remain, yours very truly,

WILLIAM BOWMAN.

King's College, London,
June 18, 1840.

POSTSCRIPT.

Having in the foregoing paper argued that the contractions of living muscle must be the same in kind with those everywhere noticed by me in animals during the last moments of life, I have now to add the confirmation of direct observation with regard to this point. In the striated fasciculi of the legs of the *Monoculus*, and of the *Argulus*, voluntary contractions may be occasionally seen to occur; a portion only of the fasciculus contracts, and may be known by its becoming broader and denser, and its transverse striæ closer to one another and narrower than before. The effect of this is a shortening of the whole fasciculus and movement of the limb in correspondence.

With respect also to the phenomena of contraction in muscle when removed from the body, I may observe that an opportunity of inspecting them in the human subject having lately presented itself, I have found them to be in every way identical with what had been previously observed in animals as herein detailed, and especially that when the fasciculi were immersed in water, bullæ were developed upon them by the elevation of the sarcolemma, and their transverse striæ were very much approximated to each other. (See fig. 79.)

July 23, 1840.

EXPLANATION OF THE PLATES.

Unless otherwise stated, the figures are represented as seen under a magnifying power of 300 diameters.

PLATE XVI.

- Fig. 1. Human pectoralis major, macerated in liquor of ammonia. Transverse section, showing the prismatic form of the primitive fasciculi. A wet specimen.
- Fig. 2. Flat primitive fasciculus, from the Staghorn Beetle (*Lucanus cervus*).
- Fig. 3. Transverse section of a large primitive fasciculus from the Skate (*Raja Batus*), showing the extremities of the primitive fibrillæ, and the corpuscles throughout its interior.
- Fig. 4. Transverse section of primitive fasciculi from the Haddock (*Gadus Eglefinus*), showing everywhere the extremities of the fibrillæ in close apposition with one another. Some few are more distinct than the rest. The disparity in size between contiguous fasciculi is here exemplified.
- Fig. 5. Transverse section of primitive fasciculi from the leg of the Frog, showing the same points.
- Fig. 6. Transverse section of primitive fasciculi from the Boa, showing the same.
- Fig. 7. Transverse section of primitive fasciculi from the pectoral muscle of the Teal (*Querquedula crecca*), showing the same. In this, the extremities of the fibrillæ are particularly evident and far apart, and at *a* the sarcolemma is seen. Treated with weak acid.
- Fig. 8. Transverse section of primitive fasciculi from the human biceps, showing the fibrillæ everywhere, but most distinctly near the surface.
- Fig. 9. Primitive fasciculus partially fractured, and its interior displayed. The fracture on the outside follows the direction of the transverse striæ, while in the interior the broken fibrillæ are of various lengths. All these fibrillæ present a series of dark and light points. From the Boa: 400 diameters.
- Fig. 10. Mass of primitive fasciculi (from the leg of a Rabbit at birth), stretched and partially ruptured. The form of the fibrillæ still connecting the broken parts is seen more highly magnified in several sketches, *b, b, b*, and also how their segments conspire to form transverse and longitudinal striæ, *c*.
- Fig. 11. Part of a fibrilla from the rectus oculi of a large fish (Shark ?) that had been long immersed in spirit, very highly magnified to show the form of the segments.
- Fig. 12. Fragment of a fibrilla from the heart of the Turtle, showing the form of the segments. Obtained by maceration.

- Fig. 13. Fragment of a fibrilla from the upper part of the œsophagus of the same.
- Fig. 14. Primitive component segments of a primitive fasciculus, arranged so as to form longitudinal and transverse striæ, very highly magnified to show the long diameter of the segments oblique to these striæ, and turned in different directions, so that the transverse striæ are broken. From the leg of a Chameleon in spirit.
- Fig. 15. Four primitive component segments of a fasciculus, united longitudinally to form a fragment of a fibrilla. Very highly magnified, and in two states of focus, to show their form and density by the varying refraction in the two states. By the lateral adaptation of a series of fibrillæ such as this, the transverse striæ would be doubled in one state of focus. From the psoas muscle of the Hare.
- Fig. 16. Several primitive fasciculi from the leg of a Rabbit at birth, macerated several months in weak spirit. On the convexity of the curve many segments of the fibrillæ are deficient, and the lateral adhesion of the remaining ones is thus made evident.
- Fig. 17. Three fragments of a macerated heart (Ox), showing everywhere marked fibrillæ, and their union to form striæ.
- Fig. 18. Two fibrillæ from a Crab, showing the segments aggregated into sets of three, and thus producing broader and less numerous striæ.
- Fig. 19. Primitive fasciculus from the neck of the Duck in two states of focus. At *a* the striæ are seven in $\frac{1}{1000}$ th of an inch, and at *b*, twenty-one to twenty-five in the same space. The striæ are oblique, by the discs being thrown, as it were, partially on their sides.
- Fig. 20. Unusual appearance of the striæ in a fasciculus of the Staghorn Beetle, observed immediately after death.
- Fig. 21. Portion of a primitive fasciculus from a Pig, showing a cleavage according to the transverse striæ.
- Fig. 22. Human primitive fasciculi, in which the transverse striæ are separated. The irregularities are due to the pressure of a lamina of mica.

PLATE XVII.

- Figs. 23. 24. 25. 26. Portions of primitive fasciculi from the leg of a Lizard that had been kept in spirit, in which all appearance of longitudinal striæ is absent, and the cleavage is into discs.
- Fig. 27. Two recent primitive fasciculi from a Sprat, showing the same points. One disc is seen detached.
- Fig. 28. Primitive fasciculus from an atrophied gastrocnemius muscle (human), showing the angularity of the striæ.
- Fig. 29. Part of a primitive fasciculus from the Boa, showing a partial separation of the discs and the untorn sarcolemma between them.

- Fig. 30. Primitive fasciculus from the pectoralis major of a human foetus at birth, showing a partial separation of the discs (which are proved by the transverse striæ to be already formed), and the sarcolemma in the interval.
- Fig. 31. Primitive fasciculus partially drawn from its sheath. From the Cod, magnified sixty diameters.
- Fig. 32. Broken primitive fasciculus from the Boa, showing a loose fragment in the tubular sheath connecting the detached portions.
- Fig. 33. Primitive fasciculus fractured, the ends drawn asunder, but retained in connexion by the sarcolemma, which is twisted. The ends of the fragments are somewhat rounded by it. From the Boa.
- Fig. 34. Primitive fasciculus (human), broken according to the discs, and the fragments connected by the untorn sheath.
- Fig. 35. Broken primitive fasciculus from the Frog, showing the tubular sarcolemma connecting the fragments, in a flaccid or collapsed state, and thrown into irregular folds.
- Fig. 36. Primitive fasciculus broken, by stretching, into several fragments, all of which are still contained in the untorn sheath. Magnified twenty diameters. From the Skate.
- Fig. 37. Primitive fasciculus partially broken up by its own inordinate contraction into its component segments. The debris all contained in the unmutilated sheath. Corpuscles are seen on some fragments. From the Frog.
- Fig. 38. 1, 2, 3. Gradational appearance of disturbances of the striæ from disunion of the primitive component segments of the fasciculus, the parts retained in contact by the sheath. From the Skate. Magnified 100 diameters.
- Fig. 39. Part of a primitive fasciculus of a Skate, swollen by liquor potassæ, showing a hernia through a ruptured aperture in the sarcolemma. In this hernia the striæ are distorted and variously curved. The corpuscles are elongated in the direction of the fibrillæ, and indicate the direction taken by the particles of the protruding mass. Detached corpuscles are represented with their nucleoli (*a*).
- Fig. 40. A similar specimen from the human subject, swollen by phosphoric acid. The herniæ are seen more completely in profile. The corpuscles are less elongated, but some have nucleoli (*a*). Their average diameter is $\frac{1}{3000}$ th of an inch.
- Fig. 41. Sarcolemma occupied by Trichinæ. From the Eel.
- Fig. 42. Trichina extruded from the sheath, and uncoiled, showing an appearance of granules. This is $\frac{1}{18}$ th of an inch long.
- Fig. 43. Another extruded worm, coiled.
- Figs. 44 and 45. Granular mass, likewise extruded; 45. has the appearance of a transparent investment.

PLATE XVIII.

- Fig. 46. Portion of a primitive fasciculus treated with citric acid. The corpuscles are evident, and some are disposed in a central row. The sarcolemma is completely burst, but fragments of it remain, and evince their attachment to the fibrillæ by preventing these from freely expanding. From the land Lizard (*Lacerta agilis*).
- Fig. 47. Another specimen from the same. Here the fibrillæ in protruding from the extremity of the sarcolemma have curled back its rim into a circular roll, *a, a*, tightly constricting the mass, and preventing the escape of fluid, which at *b* is collected between the fasciculus and its sheath. The resistance of the sarcolemma is shown by the expansion of the mass *c*, which has escaped from it. In the protruded part, the corpuscles have resumed their oval figure, though somewhat broken.
- Fig. 48. Part of a primitive fasciculus preserved in alcohol, showing the corpuscles unaltered in shape. The transparent sheath is seen at the margin. From the Frog.
- Fig. 49. Another from the same specimen, showing the adhesion between the corpuscles and fibrillæ.
- Fig. 50. Portion of a human primitive fasciculus treated with phosphoric acid, and showing the corpuscles. A filament of cellular tissue indents the surface of the fasciculus and distorts the striæ.
- Fig. 51. Primitive fasciculus from the rectus oculi of the Horse. Tartaric acid. Shows the corpuscles. Some are detached at *a* and possess nucleoli.
- Fig. 52. Primitive fasciculus from the Pig. Tartaric acid. Shows the corpuscles.
- Fig. 53. Primitive fasciculus from the larva of the Libellula, in an early stage of development, showing a row of central corpuscles.
- Fig. 54. Adult primitive fasciculus from the 'Harry Longlegs' (*Tipula*). Citric acid. Shows the row of central corpuscles.
- Fig. 55. Primitive fasciculus from the chrysalis of the Tiger Moth, surrounded by nucleated cells.
- Fig. 56. Primitive fasciculi, in a very early stage of development, bulged at intervals by the contained corpuscles, and presenting a remarkable similarity to adult fibres of the muscle of organic life, as in fig. 66. From the leg of a Chicken, tenth day of incubation.
- Fig. 57. Primitive fasciculus, with a corpuscle projecting on its surface. The transverse striæ already developed, and as broad as in adult fasciculi. From the pectoralis major of a Kitten at birth.
- Fig. 58. Mass of primitive fasciculi from the same, treated with tartaric acid, showing the corpuscles.
- Fig. 59. Loose cell seen floating near the same specimen, containing a nucleus and nucleolus.

- Fig. 60. Primitive fasciculi from the pectoralis major of a foetal Calf about two months after conception, showing the corpuscles.
- Fig. 61. Primitive fasciculi from the pectoralis major of a human nine months foetus, showing the corpuscles here and there, but obscured by the strong transverse striæ.
- Fig. 62. Mass of primitive fasciculi from the same, treated with tartaric acid, showing numerous corpuscles, turned in various directions, some presenting nucleoli.
- Fig. 63. Detached corpuscles from the same.
- Fig. 64. Detached corpuscles from the scalenus of a child two years old (made evident by citric acid).
- Fig. 65. Corpuscles in a mass of fibres from the adult human stomach, treated with tartaric acid.
- Fig. 66. Fibres from the adult human stomach, bulged at intervals by their corpuscles. Without acid.
- Fig. 67. Mass of fibres from the first stomach of a Sheep; the corpuscles made evident by tartaric acid.
- Fig. 68. Attachment of tendon to a primitive fasciculus, from the Skate. On bringing deeper and deeper portions of the specimen into focus, along the line of union between the two structures, fresh tendinous wavy filaments and striated muscular parts came everywhere into view together.
- Fig. 69. Another specimen from the same, in which the tendon is more spread out.
- Fig. 70. Two examples of the attachment of tendon to primitive fasciculi from the leg of the large Meat Fly (*Musca vomitoria*). The centres of the fasciculi are in focus, and present their row of corpuscles. The scalloped margin at *a* is the sarcolemma raised by fluid. Its attachments are seen to be to the light striæ, or the circumferences of the discs. The terminal disc is a perfect one.

PLATE XIX.

- Fig. 71. Primitive fasciculus from the Water Beetle (*Dytiscus marginalis*), contracted in water, showing the sarcolemma raised in bullæ, and a partial separation of the discs.
- Fig. 72. Smaller primitive fasciculus from the same, in water. The central portion only is contracted, and shows approximation of the striæ, increased thickness of the fasciculus, and the sarcolemma elevated in vesicles.
- Fig. 73. Primitive fasciculus from the Tipula, contracted in water, showing the sarcolemma raised by the fluid, and the central row of corpuscles.
- Fig. 74. Primitive fasciculus from the larva of the Libellula, contracted in water. The sarcolemma is raised into a large bulla.

- Fig. 75. Primitive fasciculus from the Frog, contracting in water, the two ends being fixed. The consequence is the rupture of the fibrillæ at intermediate parts, as *a*, *b*, but some fibrillæ remain attached to the sarcolemma at *a*. Bullæ are formed, *c*. The transverse striæ are much disarranged by the irregular contraction, and are besides so exceedingly fine in some parts that they cannot be represented.
- Fig. 76. Primitive fasciculus of the Newt (*Triton palustris*), contracted in water, showing the sarcolemma elevated extensively by the fluid, and thrown into transverse folds, which are independent of the fibrillæ.
- Fig. 77. Margin of a primitive fasciculus from the Chaffinch (*Fringilla cœlebs*), contracted in water; the sarcolemma raised in vesicles.
- Fig. 78. Another, with the adhesions of the sarcolemma to the fibrillæ more extensively ruptured, and a bulla formed.
- Fig. 79. A similar specimen from the fore-arm of the human subject, the limb having been amputated in consequence of a severe injury.
- Fig. 80. Primitive fasciculus from the Mouse, contracted in water. The sarcolemma much raised by the fluid.
- Fig. 81. Primitive fasciculus from the *Libellula depressa*, bent, probably by the instrument. At the concavity of the bend the striæ are approximated and the fasciculus is puckered irregularly.
- Fig. 82. Primitive fasciculus from the Blue Bottle Fly (*Musca vomitoria*), partially contracted.
- Fig. 83. Primitive fasciculus from the Staghorn Beetle, contracted in different degrees. The thickening of the fasciculus everywhere corresponds with the amount of the approximation of the striæ.
- Fig. 84. Primitive fasciculus from the land Lizard (*Lacerta agilis*), partially contracted in *syrup*, showing approximated striæ and increased thickness, but no bullæ.
- Fig. 85. Broken extremity of a primitive fasciculus from the Frog, partially contracted at *a*, while at *b* the striæ are more widely separated and its breadth is less. Here also the corpuscles are more elongated than in the contracted portion. From the same specimen as figs. 48 and 49.
- Fig. 86. Primitive fasciculus from the Eel, partially contracted in water. The contracted part is thickened, its striæ approximated, and its sheath raised from its surface. At *a*, the striæ are nine in $\frac{1}{1000}$ th of an inch; at *b*, they are twenty, and at *c*, twenty-six in the same space. At *a*, the diameter of the fasciculus is $\frac{1}{300}$ th of an inch, and at *c*, $\frac{1}{300}$ th.
- Fig. 87. Primitive fasciculus of the Skate, partially contracted, showing the contracted part augmented in thickness, with approximated transverse striæ, and more evident longitudinal striæ.

Fig. 88. Shows four stages illustrative of contraction, seen on one occasion in a primitive fasciculus of a Skate. The first state is that of rest; in the second, the striæ on one margin are approximated in sets, the contractions at the same time moving onwards. In the third state, the contractions implicate the whole breadth of the fasciculus, and still advance. In the fourth state, the striæ are everywhere approximated, the fasciculus is more opaque and thrown into close rugæ. The existence of these rugæ is an accidental circumstance, resulting from the contraction of neighbouring fasciculi (not represented in the figure) drawing the ends of this one nearer together than they are brought by its own contraction.

Fig. 89. Margin of a large fasciculus from a young Crab, in water, showing the first stage of contraction.

XXII. *An Account of Experiments on the Reflecting Telescope.* By the Right Honourable Lord OXMAWTON, F.R.S., &c.

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FOR several years I have been engaged in a series of experiments, in the hope of increasing the power of the telescope, and I am induced, perhaps rather prematurely, to lay some account of them before the Royal Society, conceiving that, from the scale upon which they have been carried on, and perhaps from their results, they may prove interesting, particularly to those who have devoted their attention to such subjects. I should have been glad to have postponed this communication to a more distant time, so as to have rendered it in many respects more complete, but as experiments on a large scale are necessarily very tedious (months, even years, passing away almost imperceptibly), to have done so would have been to have postponed it indefinitely, and to have withheld facts which may perhaps be useful to those who are engaged in similar pursuits.

All the experiments I am about to describe relate solely to the Reflecting Telescope. With the exception of a few trifling experiments many years ago on fluid object-glasses, which led to no result, I have not had any experience in the construction of the refractor.

I have long thought that in the present state of knowledge there was not much prospect of improving the refractor to any considerable extent; the fluid object-glass, at least in my hands, did not appear promising, and the improvements which have been made in the manufacture of glass on the continent, seem to have effected little more than to afford the means of constructing larger discs of tolerably perfect glass, than was formerly practicable; still wanting, however, that exact homogeneity, and indeed those optical properties essential to any great increase of power. Upon the whole, therefore, there seemed to me to be but little chance of effecting anything really important in the present state of astronomy except by improving the reflecting telescope; to that object, therefore, every effort was directed. The task was evidently a very difficult one, as the late Sir W. HERSCHEL had apparently almost exhausted the subject, having devoted to it acquirements the most varied and extensive, and at the same time the most suitable, during a very long life. Still it did not seem impossible that, profiting by his labours, and imitating his example of steady perseverance, some advance might be made, trifling perhaps, but eventually leading to valuable results.

The great object seemed to be, to remove, as far as possible, the causes, owing to

which, in increasing the size, much of the perfection of smaller instruments had invariably been sacrificed. For instance, to avoid the brittleness of the best speculum metal, it had been found necessary, as the dimensions were increased, to use an increased proportion of copper, so that the alloy was inferior in brilliancy, yellower, and much more liable to tarnish*. In polishing large surfaces also there were great and peculiar difficulties, all the defects having a tendency to augment rapidly with the size, and proportionately to impair the defining power. I thought, therefore, that were it possible to discover means of securing, in the construction of large instruments, the same excellence of material and accuracy of surface, which on a small scale was attainable by the processes already published, much would be gained; but even in the construction of small instruments there was no reason to suppose that the utmost limits of perfection had already been attained. On the contrary, the unequal performance of specula wrought with the utmost skill by the same hand, and with the same materials, was a fact which clearly proved that certainty of effect, the usual characteristic of a perfect mechanical operation, was still to be sought for. It was evident, therefore, that there was ample room for experiment with a prospect of some success. With these views, the first experiments were undertaken: they were on a small scale, the earliest as far back as 1827, and some account of them appeared at the time in Sir DAVID BREWSTER's *Journal* for July 1828. Since that time, the scale was gradually increased, till an aperture of three feet was attained, beyond which as yet I have not proceeded.

I should, perhaps, however, remark here, that although these experiments were exceedingly numerous, they were not near so tedious as might be supposed from the length of time that has elapsed since their commencement; for in the midst of other avocations, long interruptions occurred, so that probably more might have been accomplished in one-third of the time employed continuously: there is nothing, therefore, really calculated to deter others, who have the means, from devoting their time to the improvement of the reflector: the joint labour of many may effect much, and the object is of no less importance than the advancement of those inquiries in practical astronomy, in which for further progress we must now look solely to an increase in the optical power of instruments.

In describing these experiments, it will be necessary to enter somewhat into detail, so as to enable others to repeat them without much difficulty; and as success often depends upon attention to minute particulars which have only been observed after repeated failures, it will be impossible to be as concise as it would otherwise be desirable; nothing, however, shall be inserted which has not been repeatedly tried with care, and is not calculated, either by its success or failure, to be practically useful: and first as to the best materials for constructing the reflecting surface. On this subject many experiments have been tried, but upon the whole I have little to add to what is generally known: tin and copper, the materials employed by NEWTON in the

* PEARSON's *Astronomy*, p. 74; and article *Telescope*, REES's *Cyclopaedia*, SMITHSON's *Letter*.

first reflecting telescope, are preferable to any other with which I am acquainted; the best proportions being four atoms of copper to one of tin (TURNER's numbers), in fact, 126.4 parts of copper to 58.9 of tin. This alloy, however, as well as every specimen of speculum metal I have ever examined, is visibly porous when carefully tested with a microscope; a very high power is not necessary: CODDINGTON's microscope, even with its lowest power, is generally sufficient; with his highest power always so. When the copper is very impure, and the alloy has been much heated, then the pores are often easily perceptible to the naked eye: contrary, however, to what might have been inferred from this, by making the copper and tin chemically pure, we do not get rid of them altogether; pores can still be detected by the microscope, even when the metal has been melted at the lowest temperature. Good cast steel is free from pores, but cannot be hardened without cracking when of considerable dimensions: all copper is, I believe, porous, tin not so.

NEWTON, with his usual acuteness, observed this porousness in speculum metal, and considered it a serious defect; and, although, where the process of polishing is conducted in the best manner, the evil which he had apprehended, viz. the rounding of the edges of the cavities, is not perceptible, still it is probable that it always takes place in some degree, however trifling, producing a defect so mixed up with other unavoidable errors as to remain undetected. The smallest defect, however, deserves attention, and perhaps others may succeed in discovering the cause of this, which I have not: my experiments lead me to think it is in some way connected with the presence of carbon or oxygen; and that possibly by watching the toughening of copper on a great scale, a process which chemistry has not satisfactorily explained, some information might be obtained.

Upon the whole, therefore, there is at present no sufficient reason for making use of copper in any other state than that in which it can be procured from the merchant, except perhaps for the small flat metals of the Newtonian; and with block-tin in the proper proportions, we have upon the whole the best material yet discovered for the specula of reflecting telescopes. It is, however, an alloy which has always been found rather difficult to manage; it is not easily cast sound, even of moderate dimensions, by the ordinary processes of the founder, or by those which have been published by scientific men; and even when so cast is very liable to break in cooling, or afterwards by exposure to any slight but sudden change of temperature, sometimes breaking even without any apparent cause.

The difficulties appeared so great, that reflecting upon SMEATON's account of Sir W. HERSCHEL's labours, I had very little hope that any very large specula could be cast and safely polished of so brittle and untractable a material; and although some of the difficulties have been surmounted, still it is probable, that in seeking to obtain the utmost possible amount of telescopic power the state of our atmosphere admits of, the requisite dimensions will not be attained by a simple casting of this alloy. The idea, therefore, obviously suggested itself of uniting several castings into one re-

flecting surface, and as the best means of effecting that, to solder them upon an alloy of zinc and copper, (in fact, upon a species of brass,) which should expand and contract in the same proportion as speculum metal.

The experiment was tried repeatedly upon a small scale, and the difficulties which presented themselves successively surmounted, till at length a speculum of three feet aperture was completed, which bears distinctly a high power.

The evil most to be apprehended in this construction, was unequal contraction and expansion in the different changes of atmospheric temperature; that, however, seems to have been sufficiently guarded against, as I have never succeeded in detecting the slightest change of figure. It is therefore highly probable, that specula very much larger may be constructed upon this plan, and that, in fact, by repeating a number of operations, each on a scale perfectly manageable, we may obtain a reflecting surface the most brilliant, and at the same time as large as can ever be usefully employed in astronomical researches. I will now proceed with the details of the construction of the three-foot speculum. I had previously ascertained that an alloy consisting of about 2·75 of copper to 1 of zinc, gave the same contractions and expansions as speculum metal; it was necessary, however, to repeat the measurement with care, using the identical materials which were to be employed in the construction of the speculum. The following simple contrivance for obtaining the relative contractions and expansions of a bar of speculum metal, and different alloys of zinc and copper, had been employed in the previous experiments, and was again resorted to.

A bar was cast of speculum metal fifteen inches long, and one inch and a quarter square; similar bars, but only three-fourths of an inch thick, were cast of the alloys to be tried, containing a little more or less zinc than the proportions I have given. A piece of brass, consisting of 2·75 of copper to 1 of zinc, was also cast and soldered to the bar of speculum metal, as represented in Plate XX. figure 1, where A B is speculum metal, C D brass, and E F the bar of alloy, with a small excavation in the lower end fitted by grinding, so as to rest steadily on the hemispherical disc G; a thin slip of brass was also soldered at the upper end of the bar of speculum metal, and the two bars made to fit neatly there, so that when brought together, a very fine line could be drawn across them with scarcely any troublesome parallax at the joint; the whole was then immersed almost to the top in a tin vessel of water of the temperature of the atmosphere, and that vessel placed in another much larger, also containing water. Pieces of ice were then dropped into the outer vessel, so that the temperature of the whole was evenly and gradually brought down nearly to 32°; and a straight line, as fine as possible, was then drawn across both bars, and examined with a microscope to ascertain that it was perfect. The temperature was then gradually raised by pouring hot water into the outer vessel until nearly 212° had been attained, and the line was again examined with a microscope, and where the alloy had been made by mixing 2·74 of copper with 1 of zinc, and the loss in melting amounted to $\frac{1}{16}$ th of the whole, the continuity of the line was not broken in that range of temperature; according,

however, as the proportion of the zinc was more or less, the expansion of the brass bar was greater or less than that of speculum metal.

As speculum metal and brass cannot be soldered together, except on a very small scale, with certainty by the ordinary methods practised in the arts, it may be useful to mention, that all that is necessary is, first, to fit the brass and speculum metal nicely, by filing or grinding, according to circumstances; the brass is then to be tinned, and suffered to cool; the surface of the speculum metal should be scraped lightly with a sharp chisel all over; the two surfaces are to be placed in contact, and matters so managed, that a slight pressure may be applied after the fusion of the tin, and continued until it has again become solid; the temperature should then be gradually raised till the tin melts; and then, but not till then, resin applied in fusion, and also a little melted tin; if resin or tin is applied in the solid state, owing to their rapid absorption of heat in becoming fluid, they will crack the speculum metal: the surfaces may be slightly separated, so as to ascertain that the speculum metal is tinned all over, which will be the case when the temperature reaches 400° : the whole must then be suffered to cool gradually.

In casting the alloy of zinc and copper, some precautions are also necessary, not practised and not required in the arts. At the commencement of these experiments, a difficulty occurred which for some time I failed in overcoming; in making the alloy of zinc and copper, and recasting it when made, much of the zinc was always volatilized, and the amount lost differed considerably each time, though the process was conducted as nearly as possible in a similar manner, so that it was impossible to allow for it, and the composition of the alloy was therefore uncertain; a fatal objection to the whole process. The furnace was the ordinary brass-founder's furnace, the air furnace of the chemist. I found, however, that the zinc was not volatilized in its metallic state; its affinity for the copper was sufficient to prevent that, but it was first oxydized. To prevent the fresh air from beating down upon the crucible whenever the lid of the furnace was removed, the furnace was made much deeper; this was of great use, but still the air which had passed through the fuel retained oxygen enough to act considerably on the zinc. Charcoal was next heaped over the crucible, still this was not effectual; at length, charcoal in fine powder was tried in a layer two inches thick on the surface of the metal, occasionally renewed; this was effectual. The crucible, therefore, must not be filled completely, and the charcoal dust can be conveniently thrown into it, whenever required, folded up in paper. If the process has been conducted with these precautions, the loss will be about $\frac{1}{10}$ th, and almost exactly the same each casting.

The proportions of the zinc and copper having been determined, the brass work was first cast. By a reference to figures 2, 3, and 4, Plate XX., it will be at once seen in what way the materials were disposed of. Figure 2. represents one-eighth part of the whole seen in the reverse, a single casting; fig. 3. the whole speculum, also seen in the reverse; and fig. 4. the speculum seen on the opposite side previous to the soldering

on of the plates of speculum metal; fig. 5. the speculum complete, faced with sixteen plates of speculum metal. The whole depth of the brass work was five inches and a half, and weight about four hundred and fifty pounds; the sides I B (fig. 2.) were made square and true, and then tinned, and the whole bolted together with iron bolts, as represented in the figure; the temperature was then raised till the tin was in fusion, and the bolts tightened to the utmost, so as to make close joints; in this state the speculum was turned, plated with speculum metal, and polished; but it was found that the joints had not been sufficiently secured, owing to which the bracing had not produced its proper effect, and flexure was quite perceptible by its effects in the different positions of the telescope; on a close examination, there was reason to suspect that the solder was not everywhere perfect, though it had been so originally; that in the rough operation of bolting to the lathe and turning, it had been in some places detached, and had not subsequently united, though it had necessarily been fused when the plates of speculum metal were soldered on: it was evident, therefore, that tin alone was not to be depended upon in putting together a speculum of this size. The iron bolts, of course, contracting less than the brass, had added nothing to the security of the joints; brass bolts had been tried formerly in constructing a speculum two feet diameter, but they were not strong enough to bring the joints close, and were replaced by iron ones.

The plates of speculum metal were, therefore, taken off, and the joints secured in the following manner. The whole mass of brass work was imbedded in casting sand everywhere in contact with it; over it there were about three inches of sand. The sand was then removed from the centre, so as to expose a circular surface of about one inch and a half in diameter, and about forty-five pounds of very hot melted brass, in the same proportions as the brass speculum, were poured upon it in a continued stream from a perpendicular height of about ten inches: the sand having been so arranged, that after the melted brass had reached the depth of two inches, the remainder continued to flow off; the melted brass as it began to cool was therefore continually replaced with hot brass; and from the height at which it was poured, it was necessarily in immediate contact with the surface of the cold metal, and soon completely fused it, and perfectly united it in that place. This was repeated in thirty-four different places, marked by dots in the figures: it was also tried in the places marked *c, c*, (fig. 3.) but failed. When the redundant brass had been removed with a saw, and the surface made smooth, a slight hair crack was perceptible at the boundary of the fused metal, proceeding no doubt from expansion and contraction after the brass had ceased to be fluid, but before it had become ductile. This process is made use of by the brass-founder in stopping holes in defective castings; he calls it *burning*. The failure of this process at the places marked *c, c*, is a fact which it would be important to keep in view in disposing of the parts of a large speculum. As it was desirable that some further attempt should be made to secure the joint at *c, c*, holes of about one inch and a half in diameter were bored completely through at *c*, and the

intermediate brass chiseled out, as represented in the figure. They were then filled with melted brass, which was easily effected by imbedding the whole in sand; clearing the sand completely out of the spaces, and pouring the brass into each through a hole in a flat surface of sand packed in a small flask; when the brass cooled, the contraction was sufficient to draw the joint firmly together. This process may, possibly in engineering, prove useful as a means of connecting large masses of metal: I am not aware of its having before been put in practice. Conceiving that any further yielding in the joints was now impossible, the speculum was again placed on the lathe and turned to a radius of fifty-four feet, and new plates of speculum metal prepared for it.

Notwithstanding the small dimensions of these plates, none exceeding nine inches square, more difficulty was originally experienced in casting them than could have been anticipated. A great many unsuccessful attempts were made to cast them in sand, according to the directions of Mr. EDWARDS and others; they were seldom free from flaws, and, although cooled very slowly in an oven, they were extremely brittle, sometimes flying in pieces the moment they were touched, and generally breaking in the attempt to heat them again for soldering. The cause of this brittleness was evident, as the broken parts when replaced no longer fitted exactly, the metal therefore had been in a state of tension, owing no doubt to the edges of the plates becoming solid sooner than the centre.

The next plan tried was this: a number of equidistant thin plates of iron were immersed in a square crucible of cast iron filled with fluid speculum metal, so as to divide the whole mass into plates of equal thickness: this failed altogether, the plates of speculum metal were full of flaws; their contraction had been prevented by the unavoidable irregularities of the plates of iron, and crucible. Another plan was then tried, more successful than any of the preceding. A circular sawing machine was constructed, the blades were of soft iron, and while revolving were always partially immersed in emery and water; with this a block of speculum metal was without much difficulty cut into plates, which were perfectly free from flaws, and not liable to crack. Still their texture was not uniform; for about three quarters of an inch from their edges the arrangement of the particles was different from what it was in the remainder; so much so, that the edge of the plates for that distance evidently resisted the action of emery more than the remainder, and therefore probably a speculum made of such plates would not eventually be as true as if they were free from that defect. Upon this point, however, I cannot speak quite decisively; from what I have observed I have strong reasons to think it is so; but were it of any importance to determine it, further experiments would be necessary. I have a speculum two feet aperture formed of such plates; it was however polished long ago, and I have not a polishing tool of the construction I now make use of, of the proper size; so it has not had a fair trial. The same plates were also originally used for the three-foot speculum I am describing, but when it became necessary further to secure the joints,

they were taken off and spoiled, and in the meantime another process suggested itself, which seemed to be decidedly preferable.

It was evident that the flaws of so frequent occurrence in the plates formerly cast, and also their extreme brittleness, arose from the contraction of the metal in some places more than others, just at the time of transition from the fluid to the solid state. The edge of the plates always became solid first, and the central portions thus prevented from contracting were strained when no longer ductile. Were it possible, therefore, to satisfy the following conditions, viz. that heat should be abstracted rapidly and equally from the lower surface of a fluid disc of speculum metal, so that it should solidify from the bottom upwards in strata, or rather infinitely thin laminæ, the surface being the last to solidify, we should have a perfect casting; for the particles in that case being deposited, not uniformly, indeed, owing to the unknown action of the forces of crystallization, but in such a way as to fill up the interstices, there would be no flaws; and the temperature being uniform in a horizontal direction, and in the vertical varying in regular gradation from the lower surface to the upper, there would be no strain.

This, I believe, is the true principle upon which the most perfect castings can be obtained: its truth has been fully proved by practice; and, although in the arts fortunately it is not necessary often to attend to such minutiae, as the materials employed are in some measure ductile, and therefore adapt themselves to the unequal strain to which they may be subjected, still it seems probable that the not unfrequent failure of large castings under a pressure much less than they were calculated to bear is due to this cause. The management of speculum metal may be regarded as an extreme case, where all the defects of manipulation are strikingly developed.

There are evidently two ways in which it might be possible to attain the required adjustment of temperature; the one by cooling the lower surface of a mould containing the liquid speculum metal, while the heat of the upper remained undiminished; the other by constructing the mould itself, so that the lower surface should absorb the heat rapidly and the upper retain it. Both were tried; the first by making the mould itself of cast iron, in which the metal was fused, and then exposing its lower surface to the action of a jet of cold water; the result justified the theory, but the mould very frequently cracked, and where this occurred before the speculum metal had become perfectly solid, the casting was spoiled; discs were, however, obtained of different sizes, the largest eighteen inches diameter, which was merely by chance, as a mould of that size almost invariably cracks before the completion of the process. The experiment, therefore, is not worth repeating, particularly as the other plan is simple and succeeds perfectly. It is obviously to make the lower surface of the mould of iron, and the upper sides of sand; at first a simple disc of iron was tried, but although the castings were sound, there was this defect; that bubbles of air were often entangled between the iron and speculum metal, producing cavities which it was tedious to grind out: the iron disc was therefore replaced by one made of pieces

of hoop-iron placed side by side, with their edges up, tightly packed in an iron frame: the edges were brought to a smooth surface of the proper curve either by the file or lathe, whichever was the most convenient. A metallic surface was thus constructed everywhere porous; as however close the hoop-iron had been packed, the interstices suffered air to pass freely through. So successful was this expedient, that of sixteen plates cast for the three-feet speculum, not one was defective: the following particulars require to be attended to. The disc of hoop-iron should be as thick as the speculum to be cast upon it, so as to cool it with sufficient rapidity; it requires to be warm, so that there may be no moisture deposited upon it from the sand; it may be heated to 212° without materially lessening its cooling power. The metal should enter the mould by the side, as is usual in iron founding, but much quicker, almost instantaneously; one second is sufficient for filling the mould of a nine-inch plate or speculum. As to the temperature of the metal, this can best be ascertained by stirring it with a wooden pole occasionally after it has become perfectly fluid; when the carbon of the pole reduces the oxide on the surface of the metal, rendering it brilliant like quicksilver, the heat is sufficient. When the metal has become solid in the ingate or hole through which it enters the mould, the plate is to be removed quickly to an oven heated a little below redness, to remain till cold, which, where the plates are nine inches diameter, should be three or four days at least.

The metal which had filled the ingates having been separated from the plates by a file, they were fitted to the brass speculum by grinding each separately by hand upon it till brought to the same curve. The surface of the brass speculum was then scraped and tinned, and when cold all resin was removed by washing it first with spirits of turpentine, and then soap and water. The lower surfaces of the plates which fitted the brass speculum, were carefully scraped all over with broad flat chisels of thin steel, perfectly hard; it is necessary that no spot should be passed over unscraped, and that the plate should be kept perfectly dry till soldered to the speculum. The plates were then arranged in their places on the brass speculum, which had been previously placed in an oven so constructed that the temperature could be gradually and equally raised. The bottom of the oven consisted of a cast-iron plate four feet diameter, set in brick work, as if it was intended for a sand bath; the brass speculum rested upon this, with loose bricks between to protect it from radiation, so that it should acquire heat solely from the heated air; the top of the oven had a cover in four pieces, that one might be opened at a time. In about eight hours the tin on the speculum was fused, and then melted resin was poured in between the plates; tin in fusion was also applied in the same manner, and the plates moved a little backwards and forwards. As soon as from the aspect of the edges of the plates it was certain that the tin was acting on the speculum metal, the fire was almost all withdrawn, and the temperature was not suffered to rise higher. The joints of the plates were now made straight, and kept open about one-twentieth of an inch by chips of wood; the whole was then suffered to cool gradually, and in five days it was ready to be ground.

There are here also some points which it is necessary to attend to. The perfect union of the plates with the brass speculum depends upon the fact, that if a plate of speculum metal, scraped as directed, is laid upon a clean surface of tinned brass, and the temperature raised a little beyond the fusing point of tin, and then melted resin and tin applied, the plate of speculum metal will be immediately tinned all over, and the union of course will be perfect. If resin, however, is applied at the beginning of the process, and therefore exposed for hours to an increasing temperature, the resin, before the temperature has reached the proper degree, will have been decomposed, and will effectually prevent the success of the operation. In my earliest experiments, I was not aware of this fact, and was therefore obliged to turn the plates over repeatedly with a wooden tongs, to remove the decomposed resin; and, although where the plates were small this was practicable, in attempting to manage the plates of the three-foot speculum I failed: several were broken by unavoidable exposure to variation of temperature. I may perhaps as well mention, that formerly I tried the muriate of ammonia instead of resin, and also a variety of other processes, but none was completely successful but the one I have given. The resin should not only be in fusion, but where the plates are large it is more prudent to regulate the temperature by a thermometer. The same observation applies to the tin; I have found, however, that a portion of unmelted tin in the ladle, in contact with the fluid metal, was a sufficient guarantee against a too great disparity of temperature. The brick work should be perfectly dry, as a drop of condensed steam falling upon a plate would certainly crack it.

Before I proceed to the grinding and polishing of the speculum, I will conclude the remaining experiments on the process of casting. The ease and certainty with which perfect plates of speculum metal of moderate dimensions had been obtained, obviously suggested a trial of the same principles on a larger scale. A perfect disc of fine speculum metal, twenty inches diameter, was immediately obtained, and recently so large a disc as three feet was cast perfect the first attempt, and has been finished without accident.

Although the principles which guided the manipulation have been fully explained, there are some practical details necessary to success, which might not perhaps suggest themselves immediately to others who have not had the same experience in managing this intractable alloy that I have had; a few remarks may therefore be useful. The disc, when cast, was about three inches and three quarters thick, and weighed about thirteen hundred weight; the metal for it was fused in two cast-iron crucibles. In my earliest experiments, in consequence of the failure of a very large crucible of cast iron, one inch and three quarters thick, made for me at one of the principal London foundries, I concluded too hastily that cast iron would not answer. The first time the crucible was tried, after it had been about four hours in the fire, the speculum metal oozed through it; when cold the defective portion was bored out and stopped with a screw; the next time the metal oozed out in several places. The crucible was

then broken, and it was found that the speculum metal had penetrated into the iron in various directions, and a small portion of speculum metal, when analysed, yielded iron. The reverberatory furnace was therefore resorted to, but I found that, owing to the rapid oxidation of the tin, the quality of the alloy was continually changing, and the result therefore was uncertain. In the mean time I found that the affinity of speculum metal for cast iron was very slight, although for wrought iron it was considerable; that the iron detected in the speculum metal was owing to the corrosion of the wrought-iron screw, with which the hole had been stopped, and that the failure of the crucible had arisen, not from the unfitness of the material, but from defective workmanship. After some experiments in my own laboratory, I found that crucibles cast in the usual way, with the mouth down, were generally defective, the speculum metal passing through minute pores not visible externally, as quicksilver through the sap vessels of wood. When the crucible, however, was cast with the mouth up, there was no such defect; we therefore have in cast iron a material capable of being formed into crucibles of unlimited dimensions. I cast one which held fifteen hundred weight, in which the speculum metal was made, but two crucibles of half the size were manageable with less machinery, and therefore were used in casting the speculum; they were raised from the furnaces by proper tackling, and placed in iron swing frames, so contrived that each crucible of metal could be thrown almost instantaneously into the mould. The fuel I make use of is wood or peat; the latter when of proper quality is preferable, as it yields a steadier fire, without the intense heat of coke, which would without great care endanger the crucibles. The mould was made in the same manner as in casting the plates, differing from it merely in shape and dimensions; it was what founders technically call an open one. The disc of hoop-iron was made circular three feet six inches diameter, three inches and a half thick, and turned upon a lathe convex to a radius of fifty-four feet. The speculum was cast with a groove round the edge, so that it might be securely embraced by a circular clamp tightened upon it with screw-bolts, to which the proper tackling could be hooked whenever it was necessary to move it.

When the metal had become solid, but was still red-hot, a strong hoop, somewhat larger than the diameter of the speculum, was placed upon it; to this hoop a chain from a windlass, passing through the annealing oven, had been previously attached, and by the action of the windlass the speculum was drawn into the hot oven, and every opening closed; in about a fortnight it was cool, and was found to be free from blemish.

It is of course impossible to ascertain *a priori*, whether it would be practicable to obtain still larger discs of fine speculum metal by this process, and polish them without accident; possibly it might, as the principal cause of fracture, unequal contraction, no longer exists. The question, therefore, will arise, whether in endeavouring to obtain still larger specula, to approach nearer that limit beyond which it is not permitted to us to pass, the better course would be to attempt, with the risk of

failure, a single casting of very great size, or at once to have recourse to the expedient of combining together a number of small castings, a process perhaps more tedious, possibly less perfect, but more certain. However, a further comparison of the two specula as to defining power, under all circumstances, and with the utmost care, will determine the future course of these experiments; at present there is no appreciable difference referable to their very different principles of construction; they both are free from flexure in the different positions of the instrument, and have defined equally well when polished with equal success. With a single lens of one quarter of an inch focus, giving a power of about thirteen hundred, they have both shown satisfactorily the dots on the dial-plate of a watch more distinctly than a very good refractor with a much lower power.

Hitherto the processes I have described were so effectual in producing the desired result, that there seems to be but little room for improvement, except in the discovery of new and better materials, an event by no means probable; but the case is far otherwise in the remaining operation, that of polishing the speculum; there, though the experiments have been even more numerous, much still remains to be accomplished.

Before the speculum is polished, it is worked to a spherical figure by a process technically called grinding, where the mutual attrition of the speculum, and a mass of nearly equal size of some hard substance, eventually produces a figure nearly spherical; and that, notwithstanding the irregularities, however great, of the surfaces of either, or both, at the commencement of the operation. Several ingenious devices have been, indeed, from time to time, suggested, more or less independent of the process of grinding, among which, perhaps, the most remarkable is that of Mr. BARTON, who proposed to communicate the figure and the polish at once, by turning the speculum with a diamond, constrained, by very delicate machinery, to move in the proper path, and with a motion so slow that the resulting grooves should act on light as a polished surface; but when we recollect the extreme accuracy required, that an error of figure amounting to but a small fraction of a hair's breadth would destroy the action of a speculum, it is scarcely to be expected that any process can succeed in practice, which has not, like that of grinding, a decided tendency to correct its own defects, and to produce a result in which the errors may be said to be infinitely small in comparison with the errors in any of the previous steps from which it was derived. I need, perhaps, therefore hardly say that all my experiments have been directed to the one object, that of endeavouring to improve the common published process of grinding and polishing, particularly in its application to large surfaces; for although the accuracy usually attained is so great that we fail in detecting by mechanical means, among a variety of specula made at different times and by different persons, any deviation from the proper figure, still by optical means, in fact, by trial in a telescope, the defects are at once apparent; and we shall probably find among them examples of every grade of defining power, from the speculum which is almost perfect, to that which does not define at all. This dif-

ference, so great, is mainly owing to a variety of minute circumstances incidental to the process of polishing, which influence the result in a greater or less degree; among which, the most important are, variations in the extent or relative velocities of the motions by which the necessary friction is produced; alterations of temperature; or some accidental pressure during the process. With a view of obviating these causes of uncertainty at a very early stage of these experiments, a machine was constructed for grinding and polishing, where the different motions were susceptible of separate adjustment, and were all under complete control. The first trials with it were upon the whole satisfactory, and I sent a sketch of it to Sir D. BREWSTER's *Journal* for October, 1828, in the hope of directing the attention of practical men to the subject, and perhaps of raising a doubt in their minds as to the justness of a very deep-rooted opinion, that specula could not be polished successfully except by the hand; an opinion which, if unfounded, must necessarily have been a serious obstacle to improvement, by precluding the use of the only means available in making accurate experiments under circumstances identically the same, or, indeed, of trying any series of experiments on a large scale. The machine was soon after enlarged, so as to be capable of working a speculum three feet diameter as its maximum, and otherwise improved, and since that no further alteration has been found necessary. From an experience of several years, during which specula have been ground and polished with it many hundred times, I can safely say that it fully answers the purpose, and I believe, in working large surfaces, a degree of precision can, with certainty, be obtained by it, unattainable by the hand, even by accident. The machine, in its present state, is represented in Plate XX. fig. 6, and Plate XXI. where A is a shaft connected with a steam-engine; B an eccentric, adjustable by a screw-bolt to give any length of stroke from 0 to 18 inches; C a joint; D a guide; E F a cistern for water, in which the speculum revolves; G another eccentric, adjustable like the first to any length of stroke from 0 to 18 inches. The bar D G passes through a slit, and therefore the pin at G necessarily turns on its axis in the same time as the eccentric. H I is the speculum in its box immersed in water to within one inch of its surface, and K L the polisher, which is of cast iron, and weighs about two and a half hundred weight. M is a round disc of wood connected with the polisher by strings hooked to it in six places, each two-thirds of the radius from the centre. At M there is a swivel and hook, to which a rope is attached, connecting the whole with the lever N, so that the polisher presses upon the speculum with a force equal to the difference between its own weight and that of the counterpoise O. For a speculum three feet diameter I make the counterpoise ten pounds lighter than the polisher. The bar D G fits the polisher nicely, but without tightness, so that the polisher turns freely round, usually about once for every fifteen or twenty revolutions of the speculum, and it is prevented by four guards from accidentally touching the speculum, and from pressing upon the polisher by the two guides through which its extremities pass. In fig. 7. this bar is on a larger scale. I have tried a variety of contrivances for connecting the machinery with the polisher, but

the one I have described is by far the best. The wheel B makes, when polishing a three-feet speculum, sixteen revolutions in a minute; to polish a smaller speculum the velocity is increased by changing the pulley on the shaft A. The machine is in a room at the bottom of a high tower, and doors can be opened in the successive floors, so that a dial-plate of a watch placed perpendicularly over the speculum can be examined at any moment. The dial-plate is attached to a mast, so as to be much higher than the tower and about ninety feet from the speculum; and a small flat metal and eye-piece, with its proper adjustments, completes the arrangements for a Newtonian telescope. This simple contrivance has greatly facilitated the progress of these experiments. As appears in the plate, all the motions are produced by bands three inches wide, instead of the more permanent gearing of cog-wheels: although bands are liable to break, I think they are preferable to cog-wheels, because in a machine like this, which is for experimental purposes, if any part should become fast, which has happened more than once, the band falls off or breaks, and no mischief is done: it is only in a manufactory, where there are no experiments, but merely a routine of unvaried operations, that such accidents can be guarded against. One-horse power is quite sufficient to drive this machine while it is working a speculum of three feet diameter. The engine, however, is three-horse power, as from the distance of manufactories, it has been necessary to execute all the turning and casting work in my own laboratory.

The first serious difficulty which presented itself in polishing specula of considerable size, according to the common process, was this: when the layer of pitch was thin, as it must be to produce a good figure, however accurately at first it fitted the speculum, it soon ceased to do so, and the polishing did not of course proceed properly. This derangement, which in the ordinary mode of polishing by the hand is perceived at once by the feel, is as soon perceptible with the machine, because minute bubbles from the air, which has insinuated itself between the speculum and the polisher, are immediately observable. For some time this difficulty was exceedingly puzzling, and it was not until after many abortive attempts that the cause became evident: during the operation of polishing, the abraded matter, mixed with the polishing powder, is in part taken up by the pitch, but not equally over the whole surface; as, however, pitch is not sensibly elastic with a moderate pressure, wherever most is taken up, there the surface will be most prominent, and the figure of the polisher destroyed, unless the pitch can spread laterally. To allow of this lateral expansion a certain thickness of pitch is necessary, and I found, as might indeed have been anticipated, that the thickness required to be increased with the size of the speculum; in fact, if I may be allowed so to express myself, that the necessary thickness was some function of the diameter of the speculum. By using a layer of pitch sufficiently thick, a solid speculum of twenty inches aperture and a divided speculum of twenty-four inches aperture, the subjects of these and many other experiments, were made to define tolerably with a low power, and, at the same time, had acquired a high polish.

Mr. EDWARDS mentions that he had found, that, unless the pitch was of sufficient thickness, it would not preserve its figure; he had observed the fact correctly: in assigning the cause he was evidently in error, as he attributed it to the circumstance that the thin coat of pitch, as he supposed, acquired more heat from the friction than the thicker, while the reverse must have been the fact, as the thinner the imperfect conducting material, the quicker the metallic plate, to which it was attached, would have dissipated the heat, by radiation and conduction.

Mr. EDWARDS's specula were very small, and he found the thickness of half-a-crown sufficient. It was, however, evident, both as a deduction from all that had been written upon the subject, and from some experiments on small specula, that the necessity of using a layer of pitch thicker in proportion to the size of the speculum was a great evil, and was alone sufficient to make it impossible to polish large surfaces as accurately as small ones. A consideration of the theory, which I have ventured to put forward, suggested a very obvious remedy. It was very evident that by grooving the layer of pitch, provision might be made for its lateral expansion, wherever required, without so great a thickness. The experiment was first tried by reducing the thickness of pitch one-half, and making furrows in it by means of a hot iron quite down to, the metallic plate; the furrows were two inches apart, and there were two sets at right angles to each other, so that there were nowhere more than four square inches of pitchy surface in continuity. The result was, that the defining power of the speculum was immediately much improved. After many trials, however, a far better mode of effecting the same object suggested itself. The furrows were with difficulty kept everywhere open, and where there was a failure in this respect the old evil recurred, the polisher lost its figure; moreover, it was not found practicable to reduce the thickness of pitch to a minimum, which was a great object, and there were other minor practical inconveniences. These defects were all remedied by dividing the iron disc itself instead of the pitch; this could be done to any degree of minuteness required, and the continuous pitchy surface so reduced that its thickness might be made a minimum, in fact, not greater than necessary to satisfy the condition of enduring the small amount of abrasion which takes place during the time required to complete the polishing. The improvement which immediately followed this simple device was far greater than could have been anticipated, and the divided three-foot speculum, after this change, defined better with a power of 1200 than it had done before with a power of 300. Several polishers were made on this construction, the arrangement and dimensions of the grooves being somewhat different: that last used in polishing the two three-foot specula I think is the best, and a drawing of it has been annexed, figs. 8 and 9: the circular grooves were turned with a slide rest and are three-eighths of an inch deep and one quarter wide, leaving bands of continuous surface one quarter of an inch wide; the grooves at right angles are about one inch and a quarter apart, one quarter of an inch wide, and half an inch deep; they were cut with a small circular saw, under which the polisher was made to traverse on the bed of a large lathe.

The speculum was of course truly ground with the polisher first, and then the layer of pitch or resinous composition applied, the grooves remaining empty.

There are two conditions which I have found essential in producing a successful result; the one, that the polisher should fit the speculum exactly during the whole process; the other, that the resinous surface in contact with the speculum should be as hard as possible consistent with its admitting the polishing powder to imbed itself in it: without an attention to both of these, however accurately the motions of the machine may have been adjusted, however nearly a general parabolic figure may have been attained, the speculum will not define well. The first condition is satisfied by grooving the polisher, provided the resinous surface is sufficiently soft to expand laterally into the grooves when necessary; but when it is so, I have not found it hard enough to give a very true surface, and therefore the second condition is not satisfied. But here it is necessary to explain the meaning which I attach to the words *true surface*, in contradistinction to *accurate general figure*. A true surface is one which observes the law of continuity, when, in fact, the normal to the surface everywhere cuts the axis in conformity to the law of the curve, whatever that may be. In practice, the defect, which I call an untrue surface, is perceptible at a glance where it is very considerable, and the speculum is of long focus, for instance, twenty-seven feet; it is then only necessary to place the eye a few inches within the focus, while the speculum is turned to some bright object, as for instance the enamelled dial-plate of a watch, or the moon. The irregularity of the whole surface will then be apparent, more at the joints where the speculum is in separate pieces, but still more where there is a flaw or crack. The cause is obviously this: the metal under equal friction wears everywhere unequally, and therefore the inclination of the minute portions, I might almost say elements, of the surface, deviates slightly, but sensibly, and quite irregularly from the general curvature, producing an aberration independent either of general figure or aperture. A surface of speculum metal yields in the same irregular way to the action of acids, as indeed all metals do, but the more so as their texture is crystalline or fibrous. In proportion as the resinous surface is soft, and the polisher heavy, the irregularity increases, and therefore we should conclude that the harder the surface and lighter the polisher, the less the defect; and such is the fact. The accuracy of the *general figure* depends mainly upon the motions of the machine and the thinness of the resinous surface. If the resinous surface is so hard that the particles of polishing powder no longer sink into it deep enough to be held fast, then the polish is destroyed, the polishing process passing into that of grinding; long, however, before that limit of hardness has been attained, the resinous surface has lost its essential quality of expanding laterally, and therefore of preserving its exact coincidence of figure with the speculum. I have found that the two properties apparently inconsistent with each other, can be imparted to the polisher at the same time, simply by using the resinous composition of two different degrees of hardness, so as to form two very thin strata, the outer one being the harder. The resinous surface

in contact with the speculum can thus be made as hard as necessary, while the thin subjacent layer of softer resin expands laterally, so as to preserve the figure of the polisher. The process of polishing for optical purposes appears to me in some measure to resemble that of filing, the polishing powder imbedded in the resinous surface representing the teeth of the file: while the polisher preserves its figure exactly, and consequently its contact with the speculum is exceedingly close, every particle of polishing powder, as it insinuates itself between the rubbing surfaces, must be instantly forced into the resin, deeper as the resin is softer, producing a grooving or grain in the speculum, finer, if the fineness of the polishing powder is given, in proportion to the softness of the resin, and, consequently, to the depth the particles have become imbedded, and, therefore, the smallness of the portion of each which projects; but the moment the figure of the polisher ceases to be exact, then the polishing powder is no longer forced into the resin, but runs loose, producing a grain perhaps as coarse, or coarser than the size of the particles of the powder itself. Hence, therefore, in practice it is of no less importance to the production of a fine polish, than it is to the production of a fine figure, that the polisher should very exactly fit the speculum during the whole operation. I find invariably that the moment that exact coincidence ceases, the polish rapidly declines, and is soon completely spoiled. I have hitherto observed that the quality of the polish which yields the maximum of defining power is that which is technically called a black polish, provided a very fine grain is perceptible when the speculum is placed near a window. A speculum may be polished so that the surface appears black, and without grain, like a surface of quicksilver; but I have always found it necessary for that purpose, to employ a softer resinous composition than seems consistent with the production of a very true surface. Conceiving that such a polish, though I did not find it reflected more light, was likely to reflect more accurately, I tried a vast number of experiments with the view of obtaining it in conjunction with the truest surface, but hitherto without success: the subject, however, perhaps, deserves to be pursued further, and as it seems impracticable without injury to soften the resinous surface, the best chance seems to be to search for some polishing substance consisting of smaller particles than the fine peroxide of iron, the one I have always used, so as to produce a grain not exceeding the magnitude which theory has assigned as that of an undulation of light. In preparing the resinous surface for the polisher, I have for a long time employed a mixture of common resin and turpentine, instead of pitch, having previously experienced much inconvenience in polishing large surfaces from the gritty particles which the pitch I was in the habit of using very frequently contained. However, whether pitch or resin be made use of, it is absolutely necessary that the hardness should be adjusted to the proper standard with great care.

Mr. MUDGE and Mr. EDWARDS have given different directions on this subject; Mr. MUDGE recommending the pitch to be rather soft, and Mr. EDWARDS very hard; but in the common mode of conducting the operation, no precaution being used to

prevent the temperature of the speculum from progressively increasing from friction, at length a point will necessarily be attained, sooner or later, according to the hardness of the pitch, when the pitch will yield so as accurately to fit the speculum, and the polish will then rapidly improve: but should the temperature rise further before the polish is complete, the pitch will have become too soft to work a very true surface, and the speculum, even though in every other respect perfect, will not define very sharply. It is very evident that, under such circumstances, a steady temperature could not be maintained, except where the heat evolved by friction exactly balanced that dissipated by radiation and conduction, and that the result even on the limited scale of Mr. MUDGE's and Mr. EDWARDS's operations must have been uncertain; but in working large specula, the uncertainty was so great, that it gave rise to difficulties which I found it impossible to combat, and therefore I resorted to the simple expedient of making the speculum revolve in water, kept at an uniform temperature, generally 55° : all change also in the figure of the speculum, from variation of temperature during the process, was thus at the same time prevented. The hardness of the resinous surface was therefore adjusted to suit the temperature, which is thus easily effected. Common resin is melted, and when nearly boiling, spirit of turpentine is added to it, perhaps about one-fifth of its weight; but resin varies so much in quality, that there is no guide except actual trial. When the mixture has been incorporated by stirring, a cold piece of iron is to be immersed in it, and then placed for some minutes in a vessel of water at a temperature of 55° ; if then a moderate pressure of the nail makes a decided impression without splintering, it is of a proper hardness for the first layer on the polisher, and only requires to be strained through canvas. I know of no mode which in practice answers better than the very rude one of judging of the hardness by the effects of the pressure of the thumb nail: there are others more precise, but they all take too much time, and sufficient accuracy can be attained without them. For the second layer, it is mixed with one-fourth of wheat flour, which, by increasing its tenacity and diminishing its adhesiveness, prevents that accident complained of by practical men, viz. the separation of minute particles of pitch from the polisher, which afterwards run loose between the polisher and the speculum. It is to be boiled till the water of the flour has been expelled, and the mixture becomes clear, and the boiling further continued till some of the turpentine has been driven off, and the mixture has become so hard, that at a temperature of 55° , a very strong pressure of the nail makes but a slight impression: it is still too soft, and I then add to it an equal weight of resin; it will then be hard enough to produce a very true surface, and, at the same time, soft enough to suffer the particles of polishing powder to imbed themselves, and consequently to produce a very fine black polish. Whenever the resinous mixture is remelted, I suspend the vessel to the beam of a scale, counterpoise it, and take care to apply the heat so gradually as not to drive off any of the turpentine, which is immediately perceptible by the disturbance of the equilibrium. To apply the resin, the polisher is first heated to

about 150° , and the soft mixture laid on with a large flat brush, to about the thickness of one-thirtieth, or one-twenty-fifth of an inch; it is then suffered to cool to about 100° , and the hard mixture applied in the same way and to about the same thickness. When the temperature has sunk to 80° , the polisher is placed on the speculum previously covered with peroxide of iron and water, of about the consistence of thin cream. It may be well to observe, that the speculum is not endangered by applying a polisher at 80° , while it is but 55° , because the thin layer of resin retards very much the transmission of heat; but in grinding, where there is no resin, were there such a disparity, the speculum would be broken. In grinding the three-foot speculum formed in separate pieces, the iron plate happened to have been washed with warm water, and though but little warmer than the speculum, the moment it was put on several of the plates cracked, but from the construction it was but little injured: had it been the other speculum in one piece, it would of course have been destroyed.

I prepare the peroxide of iron by precipitation with water of ammonia from a pure dilute solution of sulphate of iron; the precipitate is washed, pressed in a screw press till nearly dry, and exposed to a heat which in the dark appears a dull low red. The only points of importance are, that the sulphate of iron should be pure, that the water of ammonia should be decidedly in excess, and that the heat should not exceed that I have described. The colour will be a bright crimson, inclining to yellow. I have tried both potass and soda pure instead of water of ammonia, but after washing with some degree of care, a trace of the alkali still remained, and the peroxide was of an ochrey colour till overheated, and did not polish properly. THOMSON says the peroxide of iron is sometimes of an ochrey colour, probably owing to some impurity, and I have found that the slightest trace of potass or soda produces that effect. Possibly even washing with a degree of care, too troublesome for practice, would be ineffectual in removing the last remains of the alkali, as DAVY found that silica prepared with an alkali always retained a trace of it, even after the most careful washing; but this is not exactly a case in point.

Having thus endeavoured to point out as concisely as possible what I have found essential in producing a *very true surface* and a fine polish, without at all wishing it to be inferred that I consider these processes quite perfect,—for, on the contrary, I believe much still remains to be accomplished,—I will next describe the means by which I have endeavoured to obtain a very good general figure.

When I had but little experience in working specula, considering the subject more theoretically than practically, I thought that a spherical figure was the only one which could be wrought with sufficient accuracy for optical purposes, and therefore that an original spherical aberration was an unavoidable evil; but that were it possible by any counteracting means to neutralize, or even diminish it, we might have telescopes of greater aperture with a given focal length. I constructed, therefore, a Newtonian telescope of six inches aperture, and two feet focus*: the speculum was in two concentric

* Sir DAVID BREWSTER'S Journal, July, 1828.

portions of such dimensions, that, presuming the original figure to have been accurately spherical, each should by calculation have one-half of the whole aberration: by drawing, therefore, the central portion back the proper calculated distance by a delicate screw adjustment, and bringing the images into exact coincidence, the aberration should have been reduced to one-half. The experiment was so far successful, that an instrument of eighteen inches aperture was commenced, and the castings of the speculum in three adjustable portions were completed. In the mean time, however, with additional experience, I found it necessary to adopt new views, and was soon convinced that it was not impossible to work figures which, though not rigidly accurate, were, however, better for specula than the spherical. The undertaking was, therefore, abandoned, but the original instrument still remains, and is so far curious as showing that an adjustment of such delicacy can be practically accomplished. The experiments to which I have alluded, were made with the elliptic polisher of Mr. EDWARDS, a contrivance in my opinion possessing more merit than has usually been ascribed to it: I found that a speculum of four inches aperture, and eighteen inches focus, after having been polished by hand as truly spherical as I could make it, was invariably improved by working it on the elliptic polisher; however, on applying the same principle to larger specula, the result was less successful; and after a great many trials with a speculum of eighteen inches aperture, I found it would not answer. On measuring the focal length of the surface at different distances from the centre of the *face*, it was certain that the radius of curvature always increased much too rapidly towards the edge; and when the principle upon which the elliptical polisher acts is considered, it is evident that such a result might have been anticipated, and that the defect, though scarcely perceptible in very small specula, would have been very important where the dimensions were considerable.

Having observed that when the extent of the motions of the polishing machine were in certain proportions to the diameter of the speculum, its focal length gradually and regularly increased, that fact suggested another mode of working an approximate parabolic figure. If we suppose a spherical surface, under the operation of grinding and polishing, gradually to change into one of longer radius, it is very evident that, during that change, at no one instant of time will it be actually spherical, and the abrasion of the metal will be more rapid at each point as it is more distant from the centre of the *face*. When, however, the focal length neither increases nor diminishes, the abrasion will become uniform over the whole surface, producing a spherical figure. According, however, as the focal length (the actual average amount of abrasion during a given time being given) increases more or less rapidly, the nature of the curve will vary, and we might conceive it possible, having it in our power completely to control the rate at which the focal length increases, so to proportion the rate of that increase as to produce a surface approximating to that of the paraboloid. Of course the chances against obtaining an exact paraboloid are infinitely great, as an infinite number of curves may pass between the parabola and its circle of curvature,

and it is vain to look for a guide in searching for the proper one in calculations founded on the principles of exact science, as the effect of friction in polishing is not conformable to any known law; still from a number of experiments it might be possible to deduce an empirical formula practically valuable: this I have endeavoured to accomplish.

The weight of the polisher was constant, being the least possible consistent with its working properly, viz. ten pounds for a speculum three feet diameter. The distance of the counterpoising lever would obviously influence the curve; that I have regarded as constant also, viz. twelve feet, as also, in all my most recent experiments, the length of the stroke of the first eccentric B, which was one-third of the diameter of the speculum; the only variable quantity was, therefore, the stroke of the second eccentric G. Under these circumstances, the most accurate determination at which I have as yet been enabled to arrive is, that when the stroke of the second eccentric G is such as to communicate a lateral motion to the polisher equal to about $\frac{1}{27}$ of the diameter of the speculum, the curve will be nearly parabolic. The curvature I measure as MUDGE did, by means of diaphragms; and when the surface is true, the separate portions of it, though the general figure may be indifferent, will define sharply, and their focus can be ascertained with great precision. If the surface is not true, the curvature cannot be ascertained with any degree of accuracy; the watch-dial, the test object, is but ninety feet from the speculum, and could not be placed higher without inconvenience; it is therefore necessary in measuring the curvature of the speculum to allow for its distance. This I do simply by calculating the spherical aberration, the radiant being ninety feet distant, at two points, one $\frac{1}{4}$ th of the radius, and the other $\frac{1}{3}$ rd of the radius from the centre of the *face*, deducting that from the aberration for parallel rays at these points, and endeavouring so to figure the speculum that it should be over corrected that much. Any further refinement would be but waste of time in the present state of these experiments; and although we cannot hope to obtain anything but an approximation, still the limits of error will be so small that even a large fraction of that quantity may not in practice be very important. The adjustment, however, can be made with such accuracy, that the three-foot metal at present in the telescope, with its whole aperture, is thrown perceptibly out of focus by a motion of the eye-piece, amounting to less than the thirtieth of an inch; and even with a single lens of one-eighth of an inch focus, giving a power of 2592, the dots on a watch-dial are still in some degree defined.

A watch-dial is, upon the whole, as good a test for very large specula as can be desired, as there is so much light that the magnifying power can always be increased till indistinctness is perceptible; and although eventually the performance of the instrument on the heavenly bodies, the development of new details, or the discovery of new objects, which other instruments have not reached, are the proofs that an accession of instrumental power has been obtained, still as a test to have recourse to during the progress of experiments, a watch-dial, which is always at hand, and so

near that atmospheric changes do not very materially affect the result, is a far better object.

By keeping the same principles in view, a very perfect plane speculum can be worked with facility, difficult as that operation has been found in practice. The polisher I make use of for a metal about three inches by two, is three inches diameter, divided exactly like the large polisher, but with proportionate minuteness; when the metal is polished, it is tested in the usual way by viewing an object alternately by direct and reflected vision, with a very good thirty-inch achromatic, the aperture of which has been previously contracted to an inch and three quarters. If the metal is concave, it is worked with shorter strokes for about half an hour and then tried; it will be found to have become less concave, possibly convex; in the latter case it is to be worked with longer strokes; thus with the utmost facility a metal can be worked alternately concave and convex, and, with a little practice, the limit between the two can be hit with such exactness, that even with the severe test of a thirty-inch achromatic, no deviation from the plane can be perceived, and the loss of light will be the only evidence that the rays have suffered reflexion before their incidence on the object-glass. Smaller flat metals I find it better to polish on the same polisher, several together, according to their size.

The telescope is mounted very similarly to Sir JOHN HERSCHEL's, but in consequence of its greater size and weight, I have counterpoised both the tube and the whole machine, which makes it easily manageable; so that upon the whole, though, with the experience I now have, I believe the mounting might be improved, it is sufficiently convenient. I use it as a Newtonian, as I find that, with its large aperture and short focus, the saving of light by the Herschellian construction is not at all an equivalent for the sacrifice of defining power, at least that is the result of my present experience; the indistinctness, however, from the obliquity of the speculum, does not appear to me to be so great as I should have expected, considering the size of the circle of least confusion; for this I cannot account.

To prevent flexure in specula of moderate dimensions, I find it is quite sufficient to support them in their box on three strong iron plates, each plate being one-third part of a circular area, the same size as the speculum, and a sector of it; the plates rest at their centres of gravity on points fixed at the bottom of the box of the speculum, and therefore no flexure of the box can affect the speculum. Although the same simple means would probably be effectual for specula of the largest size, in supporting specula of three feet diameter I have availed myself of the suggestion of a clever Dublin artist, Mr. GRUBB, and, at the expense of a little more complication, have substituted nine plates for the three, resting on points supported by levers, which rest on three original points; and if flexure is thus more effectually prevented, which I think it ought to be, the additional workmanship is of no importance. This lever apparatus, however, must be exceedingly substantial, quite disproportionately so, otherwise tremors would be introduced by it, attended with the worst consequences.

In selecting the materials for this communication from a vast mass of experiments, I have endeavoured to collect together such results as were most likely to be useful, and to work the whole into a shape as practical as possible, compressing it at the same time into the smallest compass: there are many minor matters of detail, which, therefore, I have unavoidably omitted; some of them possibly might be valuable to men of science, who may be disposed to take up the subject practically with a view of proceeding further than I have done. I have, however, the less regret on this account, as, although the instrument and the laboratory where it was constructed are in the centre of Ireland, the facilities of communication are such, that those who may desire further information, can easily obtain it on the spot, and form their own estimate of the performance of the instrument.

Since the commencement of last September, when the telescope was completed and in perfect working order, till Christmas, all opportunities which presented themselves for observing, not very many indeed, were taken advantage of. A considerable number of Sir JOHN HERSCHEL'S test objects were examined, and the performance of the instrument was quite satisfactory; but as to double stars, perhaps the most striking contrast between its action and that of other instruments, was the extreme brilliancy of the minute companions of large stars; for instance, the companion of Polaris, with six hundred, was very like Polaris itself in a forty-four inch achromatic, with a two and three quarter object glass. The companions of Alpha Lyre, and Rigel, were brilliant objects. As to the nebulae, though it was impossible not to feel persuaded that a larger, and equally perfect instrument would have done much more, still there was enough, I think, to justify a confident expectation, that even the present instrument will add something to the very little that is known respecting these wonderful bodies. I think I might almost venture to say that the nebulae, 27 Messier, the annular nebula in Lyra, and what is perhaps more curious, the edge of the great nebula in Andromeda, have shown very evident symptoms of resolvability; as also other nebulae less remarkable*. The appearance is that of a resolvable nebula in a telescope not quite powerful enough to resolve it completely. No such appearance, however, was observed till the power reached six hundred, and sometimes it was more decisive with powers of eight hundred and one thousand.

It is evident, therefore, that, except for the discovery of very faint nebulae, an object, perhaps, of but little interest, nothing would be effected by constructing a telescope of the greatest dimensions, unless it was at the same time proportionately perfect; that a mere light grasper would do nothing.

This instrument acts very powerfully on the lunar surface, and, as might be supposed, shows everywhere a variety of details not marked in the beautiful map of BEER

* In describing the appearance of these bodies, I am anxious to guard myself from being supposed to consider it certain that they are actually resolvable, in the absence of that complete re-resolution which leaves no room for error; nothing but the concurring opinion of several observers could in any degree impart to an inference the character of an astronomical fact.

and MÖDLER. A much higher magnifying power can also be used with decided advantage than they say has hitherto been practicable, viz. 300*: with a power of 600, and sometimes with a power of 900, many details are brought out, not visible with lower powers.

Were it practicable to construct a rectangular prism, reflecting as accurately as a flat metal, notwithstanding the thickness of the glass, there should, I think, be a considerable saving of light: I have not as yet had time to try the experiment, but I think it worth a fair trial. Such prisms, however, do not seem to have performed as well as might have been expected, perhaps owing to imperfect workmanship.

A still greater accession of light might be obtained without sacrifice of defining power, by using the Herschellian construction, were it possible to discover some means of working approximately the surface of accurate reflexion for oblique rays. I have recently tried a few experiments on a small scale on this subject, and am disposed to think the task is not hopeless; but a course of experiments on a large scale would be required to afford a decisive result. The question is not whether such a figure could be worked as accurately as a spherical one; of that I have no hope; but whether, in practice, such a degree of accuracy might not be obtained, that the mirror would define decidedly better than if it had been spherical, and as well, or nearly so, as when worked to the best parabolic figure that can be executed, and used as a Newtonian. The principle on which I have proceeded in these experiments was simply to consider the reflecting surface sought, as a portion of a paraboloid whose axis coincided with the side of the tube, the eye-piece of course placed on the axis; and in endeavouring to work that figure, I have had recourse to no other expedient than an adjustment of the motions with respect to the position of the speculum, guided by the same view of the subject which directed the attempts to work the paraboloid for the Newtonian, varied merely to suit the altered circumstances; but in the present imperfect state of these experiments it would be waste of time to enter more into particulars. I have mentioned the subject merely for the purpose of directing the attention of others to it.

SIR WILLIAM HAMILTON, in his paper in the Transactions of the Royal Irish Academy for 1828, on Systems of Rays, considers the surface as the envelope of an ellipsoid of revolution, having a constant axis, but a variable eccentricity, moved in such a manner, that while one focus traverses in all directions the surface which cuts the incident rays perpendicularly, the other focus remains fixed at the point through which all the reflected rays are to pass. I have not, however, discovered any practical means of availing myself of his very original mode of treating the subject.

To conclude, I think I may state as the results of all these experiments, that specula can be made to act effectively, cast of the finest speculum metal, in separate portions,

* Bis jetzt ist eine 300 malige Vergrößerung die stärkste die man mit verhältnissmässigem Erfolge auf den Mond anwenden konnte, p. 5, note.

retained in their positions by an alloy of zinc and copper, as easily wrought as common brass, and that they can be executed in this manner of any required size; that castings of the finest speculum metal can be executed of large dimensions, perfect, and not very liable to break; that machinery can be employed with the greatest advantage in grinding and polishing specula; that, to obtain the finest polish, it is not necessary that the speculum should become warm, but that any temperature may be fixed upon and preserved uniform during the whole process; and that large specula can be polished as accurately as small ones, and be supported so as to be secured from flexure.

To form any other than a very vague estimate of the dimensions which the reflecting telescope may yet attain, would be impossible. Without allowing for further improvements in the process of polishing, which certainly may be confidently anticipated, I think that a speculum of six feet aperture could be made to bear a magnifying power more than sufficient to render the whole pencil of light available, and that in favourable states of the atmosphere it would act efficiently, without having recourse to the expedient which *Newton* pointed out as the last resource, that of observing from the summit of a high mountain. The construction, however, of such an instrument would be a serious task, and I should be sorry to attempt it, till, after additional experience in observing, and further opportunities of comparing the two three-foot specula already finished, I felt more competent to do justice to the undertaking. In the mean time, I hope to receive from scientific men suggestions, which would be most valuable; to continue the experiments already in progress, and to arrange the details of the mechanism necessary to render so large a tube conveniently manageable. Everything, then, having been previously determined with care, subsequent alterations would not be required; tedious experiments would not now be necessary, either in constructing the speculum, or in the less interesting but necessary task of acquiring a practical knowledge of the mechanic arts; and an instrument even of the gigantic dimensions I have proposed might, I think, be commenced and completed within one year.

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XXIII. *Researches in Embryology. Third Series: A Contribution to the Physiology of Cells.* By MARTIN BARRY, M.D., F.R.S., F.R.S.E., Fellow of the Royal College of Physicians in Edinburgh.

Received April 18,—Read May 7, 1840.

THE "Second Series" of these Researches† traced certain changes in the mammiferous ovum consequent on fecundation. It is the object of the present communication to describe these changes more minutely, as seen by the aid of powerful lenses; and to make known a remarkable process of development thus discovered.

In order to obtain more exact results, my observations were still made on the same animal as before, namely, the Rabbit, in the expectation that, if these labours were successful, it would be comparatively easy to trace the changes in other Mammals.

By pursuing the method of obtaining and preserving ova from the Fallopian tube, which I recommended in my last paper, I have been enabled to find and examine 137 more of these delicate objects; and have thus had ample opportunity for confirming the principal facts therein stated. I have now procured in all 230 ova from the Fallopian tube. But being aware that repeated observations alone are not complete in researches of this nature, unless extended to the very earliest stages, I again specially directed my attention to the ovum still within the ovary, with a view to discover its state at the moment of fecundation, as well as immediately before and after.

(The measurements throughout this paper, as in former ones, are stated in fractions of a Paris line, and thus expressed (")). As a simple mode of reducing this fraction into (what is very nearly) the equivalent fraction of an English inch, I recommend multiplying the denominator of the former by $11\frac{1}{4}$ ‡. The actual sizes of the ova are represented at the foot of each Plate. To admit of comparison in size, great care has been taken to preserve a fixed scale in the figures, as well for the contents of the ova as for the ova themselves; this being for the most part 100 diameters. In a few instances 50 diameters have been used; and for parts of ova, figured separately, 300 diameters. The Plates have been explained (par. 430.) with considerable minuteness, in order to admit of details being as much as possible avoided in the memoir.)

322. I am not aware that we hitherto possess any drawings of ova from the ovary, either as prepared for fecundation or showing its effects. In this memoir Plate XXII.

† Philosophical Transactions, 1839, Part II. p. 307.

‡ See the "Table of Measurements" (par. 429.).

has been devoted to the former, and Plate XXIII. to the latter object. In the upper row of figures of Plate XXIV. I have copied the only delineations published by others of ova from the Fallopian tube. The amount of information obtainable from these, will be seen on comparing with them eleven states of ova from the Fallopian tube, figured in my "Second Series†," and upwards of thirty more in the present paper‡.

323. It was stated in my last memoir§ that the Purkinjean, or germinal vesicle, does not disappear at the period previously supposed; but that after fecundation it returns from the surface to the centre of the ovum. My later researches have not only established the fact now mentioned, but they also enable me, I believe from actual observation, to make known the destiny of this important object. These investigations realise the almost universal supposition that the germinal vesicle is the essential element of the ovum; but how far they realise any of the speculations of physiologists as to what becomes of it, will be seen on comparing the facts about to be recorded, with opinions quoted in the Appendix to this memoir.

The Doctrine of "Cells."

324. I formerly mentioned|| that SCHWANN¶, basing his researches in the animal, upon the discoveries of SCHLEIDEN†† in the vegetable kingdom, had demonstrated that in development the same phenomena are exhibited in both; that he had shown animal tissues in general, like those of plants, to be reducible to modifications of vesicles or "cells;" and that the mode of origin of the cells is essentially the same in animals as SCHLEIDEN had discovered it to be in plants. SCHLEIDEN had found, that the membrane of each cell is formed at the surface of the object previously known as the nucleus of the cell; and in the nucleus he discovered a nucleolus. As the nucleolus, the nucleus, and the cell, are objects which must in future be considered of the first importance in the structure of organized beings; as they are constantly referred to in the following memoir; and as my observations on two of these objects do not, in all respects, accord with the experience of others, it is essential to state existing views regarding them. These will be found in the Appendix (par. 425.).

CHANGES IN THE OVARIAN OVUM PREPARATORY TO FECUNDATION.

(These are represented in Plate XXII. The ova there seen measured in diameter from $\frac{1}{15}^m$ to $\frac{1}{11}^m$.)

† *L. c.*, Plate VI.

§ "Second Series," *l. c.*, par. 133.

¶ *Mikroskopische Untersuchungen über die Uebereinstimmungen in der Struktur und dem Wachsthum der Thiere und Pflanzen*, 1839.

†† Beiträge zur Phytogenesis, MÜLLEN's Archiv, 1838. Heft II. p. 137.

‡ Plates XXIV., XXV., XXVI., XXVII.

|| "Second Series," *l. c.*, par. 358.

Preparatory Changes in the Germinal Vesicle and Germinal Spot.

325. The germinal vesicle (*c*) does not "burst," "dissolve away," or "become flattened," on or before the fecundation of the ovum, as hitherto supposed. It ceases to be pellucid; and this perhaps is one cause of the mistaken views regarding it. But another cause is possibly a less transparent state assumed by the surrounding substance; and a third is doubtless the almost entire absence of observations on mammiferous ova at this period.

326. The germinal vesicle fills with cells, and these become filled with the foundations of other cells; so that the germinal vesicle is gradually rendered nearly opaque (Plate XXII. fig. 164. *c*). The mode in which this alteration takes place, is the following; and it is one which, if confirmed by future observation, must modify the views recently advanced on the mode of origin, the nature, the properties, and the destination of the nucleus in the physiology of cells. Some minute details are unavoidable; but their introduction here will save future repetition.

327. The germinal spot (*b*) is known to present in some instances a dark central point†. I find that such a point always makes its appearance at a certain period; that it enlarges, resembles a dark globule or ring, and contains a cavity filled with fluid, which is exceedingly pellucid. That which originally constituted the germinal spot assumes the appearance of incipient cells‡ (Plate XXII. fig. 156. *b*). These, enlarging, gradually come to occupy the whole of the interior of the germinal vesicle, except that part from which they rose. In the ovum, fig. 157, that which had been a dark point presented a finely granular appearance, with a central pellucid cavity. In a subsequent condition (fig. 159.), the part corresponding to that just referred to, as finely granular, had distended, and presented a layer of incipient cells; while in its interior there had arisen another object having a finely granular appearance, and likewise a central cavity. In the more advanced ovum of figs. 160 and 161, the germinal vesicle contained no less than four concentric layers, arisen in the order just mentioned, and surrounding a pellucid central space, which was exceedingly minute. The germinal vesicle in the ovum, fig. 162, presented an appearance of the same kind, but seemed to be in a condition yet more advanced. Besides three concentric layers of cells, a space was seen in the interior (included by the dotted line, fig. 163.); and in this space were two other concentric layers of cells, in a still more incipient state,—these also surrounding a pellucid centre§.

† R. WAGNER, *Prodromus Historiæ Generationis*, 1836. SCHWANN, *l. c.*, p. 54.

‡ My friend R. WAGNER with reference to the ova of squamous Amphibia and cartilaginous Fishes, remarks, "Also where the germinal spot is single only, and in riper ova, there are sometimes found to arise granulations, in the form of minute scattered globules on the inner surface of the germinal vesicle, whereupon the original larger and opaker germinal spot becomes less distinct and disappears." (*Lehrbuch der Physiologie, Erste Abtheilung*, p. 33, 1839. *Prodromus*, &c., figs. 24. and 27.) This eminent observer appears also to have seen the external portion of the germinal spot in the mammiferous ovum undergoing the change I have above described (*Lehrbuch*, &c., Tab. II. fig. viii.), though the nature of that change remained concealed.

§ The changes above described, as taking place in the germinal spot, may assist to explain its altered ap-

328. As the foundations of new cells successively make their appearance in the interior of the altered germinal spot, the pellucid central cavity in the latter presents changes in its size, and sometimes is scarcely or not at all to be discerned (compare in Plate XXII. figs. 161 and 166.), whence I conclude that the foundations of new cells in question, have their origin in the pellucid fluid of that central cavity. This remark applies to all the nuclei referred to in this memoir; and I apprehend it will be found, in connection with what has been stated in the preceding paragraph, that the nature and the varying appearance of the nucleolus of Dr. SCHLEIDEN may be thus explained.

329. Each of the objects in the germinal vesicle (c) which I have called cells or incipient cells, presents with more or less distinctness, an interior indicating the operation there of a process essentially the same (see Plate XXIII. fig. 169.) as that which gives origin to the concentric layers, in one of which the object itself is contained.

330. The germinal vesicle passes from the globular into a flattened form †. In the ovum, Plate XXII. fig. 158, it resembled in its form the crystalline lens of the eye (fig. 159.). It also becomes very much enlarged ‡.

331. The position of the germinal vesicle does not change, but it becomes more determinately applied to the investing membrane than in the immature ovum; whence the peculiar form of this vesicle in fig. 159. The pellucid part of the altered germinal spot, at which the foundations of new cells arise, is directed towards the surface of the ovum (figs. 156 to 167.) §. More particularly, the part in question is directed towards an attenuated region or an orifice (figs. 165. 167.), to be presently mentioned as observed in the thick transparent membrane f. In one or two instances, indeed, this part appeared as if protruded into the orifice; and I could not discern a continuation over it of the membrane of the vesicle.

*Preparatory Changes in the thick transparent Membrane, or "Zona Pellucida."—
The Point of Fecundation.*

332. In my "Second Series," it was stated that I had found Spermatozoa on the ovary||. From the facts just mentioned, and those about to be recorded, it may, I think, be inferred that the fecundating element of the seminal fluid penetrates, not only into the ovary, and into the interior of the ovum, but into the germinal vesicle,

pearance after maceration ("Second Series," l. c., Plate V. fig. 89. b.), for each of the several layers of incipient cells into which a nucleus resolves itself, we shall hereafter find frequently to become circumscribed by a proper membrane.

† Resembling that figured by R. WAGNER in a very mature ovarian ovum of the Frog. (Beiträge zur Geschichte der Zeugung und Entwicklung, tab. ii. fig. 6. d.).

‡ See the Table of Measurements, par. 429.

§ R. WAGNER remarks, with reference to the unaltered spot, that it appeared to him to be always directed towards the surface of the ovum (Beiträge, &c., p. 24.).

|| A note was added, yielding the priority of this discovery—made, however, in another Mammal, the Dog—to Professor BISCHOFF.

and even into a certain part of the altered germinal spot. We have seen this part tending towards the surface of the ovum. I have now to add, that in that region of the thick transparent membrane *f*, towards which this part was tending, I have in many instances observed an attenuation or an orifice. This has been noticed not only as early as the fourth hour (fig. 165.), but in very mature ova †, even *ante coitum*. The form of the orifice in question is sometimes such as to suggest the idea of the membrane having become cleft; in some instances appearing to have been first attenuated also.

333. Should this observation be confirmed, I think we shall be in possession of very strong presumptive evidence that the central part of the altered germinal spot is the point of fecundation. In further proof that such really is the case, another fact will be hereafter given (par. 346.).

334. On one occasion, in an ovum of $5\frac{1}{2}$ hours (fig. 167.), I saw in the orifice of the membrane *f*, an object very much resembling a Spermatozoon which had increased in size. Its large extremity was directed towards the interior of the ovum. Fig. 168. represents a portion of this object; the remainder having been too indistinctly seen to admit of delineation. The part figured seemed discoid in its form, and appeared to contain a pellucid and nearly central cavity ‡.

335. Around the orifice in the membrane *f* (Plate XXIII. fig. 173.), the tunica granulosa presents the effects of the determinate pressure by which the ovum had been held in contact with the wall of the ovarian cavity §.

Preparatory Changes in the Substance by which the Germinal Vesicle is surrounded.

336. This substance, usually called the "yolk," was described in my last paper, as ceasing to contain separate oil-like globules when the ovum becomes mature; and as presenting a peripheral stratum which sometimes appears granular, and at others seems to consist of vesicles (cells), pressed together into a polyhedral form, its centre being fluid. The accuracy of this description, several conditions of the ovum represented in Plate XXII. confirm; and later observations enable me, I believe, to point out the order of these different appearances, as well as the process to which they are referable.

337. If fig. 156. be closely examined, the substance lying under the membrane *f* will be seen to have consisted of a layer of very regularly elliptical and flattened objects, each of which contained minuter objects of the same kind, concentrically arranged around a pellucid point. These discoid objects, the containing as well as the con-

† From the same Rabbit as the objects in figs. 158. 159. This Rabbit exhibited marks of the most perfect preparation for the male.

‡ I am not prepared to say that this was certainly a Spermatozoon, but it seems proper to record the observation.

§ See remarks on the office of the Retinacula ovi in my "First Series." Philosophical Transactions, 1838, Part II., p. 86.

tained, are the foundations of cells; and it is important to observe, that all the cells met with in the ovum in this "Third Series" of Researches, have at first the same remarkable form, and seem to pass through a state essentially the same as that now described, and which is represented in outline on a larger scale in Plate XXIII. fig. 177. In the ovum Plate XXII. fig. 157. the objects on the inner surface of the membrane *f* appeared to have undergone partial liquefaction. Sometimes these discoid objects constitute a layer of considerable thickness (figs. 160. 167.); at others, the outer discs—or cells into which the discs have passed—seem more or less broken down, and a globular mass of smaller discs has come into view in the interior (fig. 162. 165.); and these smaller discs, in their turn, become pushed out by a fresh set into the external situation previously occupied by others, which have disappeared by liquefaction. In all the ova just referred to, there appeared to exist a central cavity filled with fluid. In the ovum fig. 160, a few pale globules were observed in this fluid.

338. Layers of the discs or cells in question are frequently seen to have become circumscribed by a proper membrane—the membrane *e* of my "First" and "Second Series." Such was the case with the layer lying under the membrane *f* in the ova figs. 162. 164. 165. 167. In other states of the ovum no such membrane is present.

339. It appears that one of these membranes having formed around the discs or cells under the membrane *f*, it subsequently disappears on the liquefaction of the objects it surrounds; when a new set of discs or cells, taking their place, becomes in like manner circumscribed by a proper membrane, destined in its turn to disappear. In like manner several membranes (*e*) successively arise and disappear in a single ovum, as layers of discs or cells become pushed out and take the place of previous layers. This will, perhaps, serve to explain why some observers have never seen a membrane under the thick transparent membrane *f*; for, as several of the figures in Plate XXII. serve to show, there are periods when no such membrane is present.

CHANGES IN THE OVUM IMMEDIATELY AFTER FECUNDATION, AND BEFORE THE OVUM LEAVES THE OVARY.

(These are represented in Plate XXIII. The ova there seen were of periods varying from $5\frac{1}{2}$ to 10 hours, and they measured in diameter from $\frac{1}{15}^m$ to about $\frac{1}{11}^m$.)

Changes in the Position, Form, and Internal State, of the Germinal Vesicle immediately after Fecundation.

340. It will presently be obvious that, without a knowledge of the fact that the germinal vesicle returns to the centre of the ovum†, it is not possible to learn the

† This remarkable alteration—occurring while the ovum is, still within the ovary—was mentioned in my "Second Series," among the facts rendering it probable that the ovary is the seat of impregnation.

mode, the period, or the place of origin of the new being; or indeed to understand the ovum in any of its future phases.

341. In Plate XXIII. fig. 169. is an ovum of $5\frac{1}{2}$ hours, in which the germinal vesicle was apparently undergoing this change of place; a change which appears to me sufficient in itself to show that an ovum has undergone fecundation†. The vesicle had begun to regain its globular form. The point of fecundation, however, was still visible at the periphery; whence, and from the unclosed state of the fissure in the membrane *f*, I am disposed to think the ovum had not been long fecundated, for the point of fecundation is subsequently seen to occupy the centre of the germinal vesicle, as was the case in the ova, figs. 171. 173. 174. 180.; and soon after fecundation the orifice in question is no longer seen.

Changes in the Substance by which the Germinal Vesicle is surrounded.

342. In the ovum fig. 170. the germinal vesicle, having receded from the surface into the interior of the ovum, had become closely surrounded by a layer of cells, each of which presented a remarkably opaque nucleus‡. Subsequently this nucleus seems to resolve itself into cells, and the same origin of new cells appears to take place in its interior, as that which I have described in a former page (par. 326 to 328.).

343. It appears also that new layers of cells come into view internal to the layer just described; when a succession of the same changes takes place as those already mentioned. Layer after layer of cells makes its appearance in the interior,—often seen to have become circumscribed by a proper membrane (*e*),—while cells occupying a more external situation undergo liquefaction. (See the explanation of figs. 170 to 176.)

† I quote the following from a high authority. "*Difference between the fecundated and unfecundated ovum.*—In the first place, in reference to this subject, it would be interesting to know whether any material difference exists between the structure of the fecundated and unfecundated egg. Did any difference of structure exist, we should be disposed to look for it first in that part of the egg which is more immediately connected with the new being, viz. in its germinal portion; but we regret to say that the investigations of naturalists have not as yet pointed out any marked difference in a satisfactory manner. Nor can we with certainty fix on what part of the egg the influence of the male semen more immediately operates. Since the fœtus grows from the centre of the germinal layer, it has been commonly supposed that this is the part of the egg which is most immediately effected by fecundation, but we know nothing of this; and it might be held on the other hand, that the effect of fecundation operates on the rest of the contents of the egg in enabling them to be assimilated round the germinal centre or rallying point of the development of the new being." ALLEN THOMSON, in Dr. TODD'S *Cyclopedia of Anatomy and Physiology*, Article "Generation," pp. 462 and 467.

‡ In the ova, figs. 170. 171., the situation of the germinal vesicle was not quite central. The cells surrounding it in these figures correspond apparently to the ellipsoidal mass figured in my "Second Series" (*i. e.*, Plate I. figs. 96 and 97.), as seen with a lower magnifying power.

Disappearance of the Orifice in the thick transparent Membrane ("zona pellucida") after Fecundation.

344. This orifice I have in no instance seen after the discharge of the ovum from the ovary†. It was distinct in an ovarian ovum of six hours (figs. 173 to 175.), certainly fecundated; in another ovarian ovum from the same Rabbit, which had also undergone fecundation, no trace of it could be seen. It is very possible, however, that in the latter instance, as well as in others where I have failed to find it, the opening was situated on the under surface of the ovum. Very probably the fissure, for such it generally seems, closes before the ovum leaves the ovary.

Changes in the Tunica granulosa immediately after Fecundation.

345. The cells of this structure undergo a remarkable alteration in position, size, form, and internal condition. Being first loosened and made less adherent to one another, they become club-shaped, greatly elongated (some of those in Plate XXVIII. fig. 245. measured $\frac{1}{30}''$ in length), and connected with the thick transparent membrane *f* by their pointed extremities alone (Plate XXIII. figs. 173. 181., Plate XXV. fig. 195.). They present in their interior, at the large extremity, a pellucid space (Plate XXVIII. fig. 245. *a.*), apparently corresponding to the *enlarged nucleolus* of other cells‡. This space is surrounded by dark globules. Subsequently there is seen instead of this pellucid space, a cell-like object which contains a colourless and transparent fluid (fig. 245. *β.*), but does not exhibit any proper nucleus or "cytoblast," and the surrounding globules become scattered. At a later period (fig. 245. *γ.*), these cells of the tunica granulosa are found filled with other cells§.

CHANGES IN THE OVUM AFTER ITS DISCHARGE FROM THE OVARY.—ADDITION OF THE CHORION.

(These changes are represented in Plates XXIV., XXV., XXVI., and XXVII. The ova there seen were of periods varying from 11 to 76½ hours, and they measured in diameter from $\frac{1}{14}''$ to $\frac{1}{3}''$ ||.)

The Germ or Foundation of the New Being; its Place of Origin and Form; the Germinal Vesicle not a Nucleus, but a Parent-cell.—Reproduction of succeeding Cells.

346. In a former page (par. 327.) it was shown that the free portion of the germinal

† See, however, "Second Series" *I. c.*, par. 178. fig. 109, and par. 190.

‡ Compare with "First Series" *I. c.*, fig. 44. *g'*, and fig. 73, "Second Series" *I. c.*, figs. 102. *g*, *g*, 88. 89. 93. 96. 97. *h.*, 103½. 114. 115. 116. *bb.*, 118. 120. 121. A. B. C. D., 122. *bb'*, 129. 132. 135. 138. 139. 148. 149. 150. 152. 153. 154. See also a great number of figures in the present paper.

§ The second and third of these conditions, however, so far as my observations have extended, are not generally met with until the ovum has been discharged from the ovary.

|| Figs. 198 and 201. in Plate XXV., represent ova of only 5½ hours from the ovary. Their unusually advanced state rendered it proper to place them among ova from the Fallopian tube.

spot having resolved itself into cells, layers of the foundations of other cells come into view around a point which had been the centre of the spot; and that these, enlarging, are succeeded by layer after layer of the foundations of yet other cells. The central point, it will be recollected, lies immediately under the orifice in the thick transparent membrane *f*, apparently for the purpose of receiving the fecundating element of the seminal fluid. It must be the point of fecundation. Here we saw a minute cavity, with dark walls, and containing a pellucid fluid. This point, as already stated, subsequently passes from the periphery of the germinal vesicle to its centre. In the latter situation, two incipient cells come into view (Plate XXIV. fig. 187. *bs*), having essentially the same form and general appearance as the cells of other parts of the ovum described in this memoir; but in general attaining a more considerable size (Plate XXV. figs. 198, 199. *bs.*), and being objects of much more importance. These two cells constitute the foundation of the new being,—that is, the germ.

347. In the ovum, Plate XXIV. fig. 191. *bs.*, they measured in length $\frac{1}{30}''$, and contained in a transparent fluid, a nucleus having a central situation. The nucleus of one of them is represented more highly magnified in fig. 192. Its external part consisted of the foundations of new cells. Its interior presented a cavity, apparently globular in form and filled with fluid, which was colourless and remarkably pellucid. The nucleus in this instance measured in diameter $\frac{1}{150}''$; from which it will be seen that the cavity in its interior could not have exceeded about one-third of this size, namely, $\frac{1}{450}''$, as the proportions were carefully observed in the drawing†.

348. The nucleus in each of the twin cells, which together constitute the germ, undergoes essentially the same changes as those presented by the germinal spot (par. 327. 328.); but seems to pass sooner than the centre of the altered spot to the interior of its cell‡. The nucleus having increased in size, dark objects—the foundations of new cells—come into view in its interior (Plate XXV. fig. 199. *bs.*); and these, enlarging, present a set having a still more central situation (fig. 200.). The pellucid centre of the nucleus eventually increases considerably in size (Plate XXVI. fig. 206.).

349. The two cells (*bs*) which constitute the germ distend, until they nearly fill the germinal vesicle (*c*). This takes place at the expense of the surrounding cells, with which it will be recollected that the germinal vesicle had filled (par. 326.). These surrounding cells, having successively enlarged, disappear by liquefaction; the outer layer of them being apparently the first to undergo this change. The inner layers § are at first pushed forth by the two distending cells (Plate XXIV. fig. 193. *bs*), but

† This remark is applicable to every other figure; so that where the size of the whole object is given (see the Table of Measurements, par. 429.), that of its parts may be inferred.

‡ It will be obvious why the central portion of the altered germinal spot continues up to a certain period at the surface of its cell.

§ These layers of cells within the germinal vesicle, and around the germ, are sometimes seen to be circumscribed by a proper membrane (fig. 193.); so that here, within the germinal vesicle, we find apparently the same process in operation as that above described (par. 339.) as forming proper membranes (*e*) under the thick transparent membrane *f*.

eventually liquefy, and thus the contents of the germinal vesicle (*c*)—again reduced to fluid—enter into the formation of the two central cells, these being destined to succeed it. The membrane of the germinal vesicle (*c*), distended to a large size,—and still present in the ova, figs. 193. 195. 198—disappears by liquefaction. This vesicle is thus, not a "cytoblast," as supposed by SCHWANN, but a parent cell: and of the numerous progeny of cells which arise within it, only two remain as its successors†.

350. While the changes just described are in progress within the germinal vesicle, membranes (*e*) continue to form and then disappear successively around the layers of discs or cells, by which this vesicle is surrounded (par. 339.). Those membranes present at this period a high refracting power (Plate XXIV. fig. 193, Plate XXV. fig. 194. *e*.), and in some instances resist considerable pressure without being ruptured‡. Very soon, however, the substance they invest has wholly disappeared, and its place is occupied by colourless transparent fluid. In this fluid there are often found solitary cells, the remains of the substance just referred to (Plate XXVI. fig. 206.). It is also very common to meet with these solitary cells in previous conditions of the ovum (Plate XXIV. figs. 187. 193.), before the last of the membranes *e* has disappeared§.

351. An appearance frequently met with as the cells which surround the germ attain their greatest size, is represented in Plate XXIV. fig. 188, and more highly magnified in fig. 189. It seems to be produced in the following manner. Every cell within the ovum, which attains a size admitting of examination, appears to be filled with the foundations of other cells, arisen in the manner before described, and arranged in concentric layers around a pellucid cavity. The outer layers liquefy, leaving the central ones as dark isolated objects in a comparatively transparent fluid (fig. 189.). The membrane of the cell remains. Between the membranes of these cells there are also minute cells present in great number, which also have a high re-

† In my "Second Series" (*l. c.*, par. 317.) I erroneously applied the term "parent cell" to the membrane *e*.

‡ "Second Series," *l. c.*, par. 171, Plate VI. fig. 103. *β*.

§ The membranes *e*, instead of liquefying, may perhaps contribute to the thickening of the thick transparent membrane *f*. Some observations mentioned in my "First Series" (*l. c.*, Plate V. fig. 17. *f*, *e*.) suggest, indeed, the consideration whether the membrane *f* may not be formed by a succession of the membranes *e*. The membrane of the ovisac (*A*) was stated in that memoir (*l. c.*, par. 23.) to appear to form around a mass of granules, since found to be cells. I have now to add, that these cells seem to coalesce for the formation of that membrane; and not only for its formation, but for its thickening also (compare in my "First Series" the thickness of this membrane (*A*) in certain figures of Plate VIII. with its original condition in Plate V.); the membrana granulosa appearing to be the medium through which the latter part of the process is effected. It would thus appear that the ovisac (the foundation of the Graafian vesicle) is a great cell, as well as possibly the thick transparent membrane *f*. The substance surrounding the germinal vesicle in certain states, exhibits changes similar to those presented by a nucleus; namely, a succession of discs or incipient cells in concentric layers, and the formation of a membrane, or rather a succession of membranes, *e*, at the surface of those layers (par. 339.). So that the substance in question seems to be a great "cytoblast."

fracting power. The ovum Plate XXIII. fig. 179, from the ovary, presented an appearance which differed only in degree from that just referred to; and I do not recollect to have met with the twin cells in stages such as those represented in Plate XXIV. figs. 191. 193, Plate XXV. figs. 196. 199, without finding them invested by minute dark objects, of apparently the same nature.

351½. The greatest size to which the germinal vesicle distends I do not know. In the ovum Plate XXV. fig. 198, it had a diameter of $\frac{1}{15}$ ''' ; that is, I believe, double what it had been seen to measure before fecundation in this animal†. In another instance (Plate XXIV. fig. 193.) it was as large as $\frac{1}{12}$ ''' . I am disposed to think that this vesicle sometimes attains a still greater size; and indeed that its membrane may continue until after the disappearance of the last of the membranes *e*; for states of the ovum are met with, in which it is not easy to determine whether the membrane surrounding the central sphere of cells (Plate XXV. fig. 204.) is that of the enlarged germinal vesicle, or the last of the membranes *e* in a very attenuated state. In those figures where neither *c* nor *e* is affixed to the representation of a membrane in this situation, it may therefore be inferred that I have felt uncertainty in this respect.

352. It has been already shown that the germinal vesicle—or original parent cell—disappearing, twin cells succeed it (Plate XXVI. figs. 206. 207. 208.). I have now to add, that each of these twin cells gives origin to two others, making four (fig. 209.); that each of these four, in its turn a parent cell, gives origin to two, by which the number is increased to eight (figs. 213 A. 213 B.); and that this mode of augmentation continues, until the germ consists of a mulberry-like object, the cells of which are so numerous as not to admit of being counted (Plate XXVII. figs. 230. 231.). Together with a doubling of the number of the cells, there occurs a diminution of their size. This will be easily seen on reference to the figures, these being for the most part on the same scale.

353. Nor does the mode of propagation continue the same with reference to number only. The process inherited from the germinal vesicle by its twin offspring, reappears in the descendants of these. Every cell, whatever its minuteness, if its interior can be discerned, is found filled with the foundations of new cells into which its nucleus has been resolved. These foundations of new cells at an early period (in the existence of a parent cell) are arranged in concentric layers around a pellucid point (Plate XXVII. fig. 230.); subsequently they are larger (fig. 231.); at a later period, when the outer layer has partially liquefied and presents its remains as minute cells (Plate XXVI. fig. 210.), the inner cells have increased in size; and at a period still more advanced, each cell presents two (fig. 222.) destined to succeed the parent cell, the others having disappeared by liquefaction. It is very possible, however, that though the same in kind, the process may, with a diminution in the size, lessen in degree. The number of concentric layers, for instance, arising in such minute cells as those

† The Rabbit.

Plate XXVII. fig. 230, may not equal the number arising in the germinal vesicle or original parent cell.

354. Very interesting states of the germ are met with, representing the transition between what in my last memoir, for a temporary purpose, were denominated "stages." Two or three of these will be found among the figures, and may serve as specimens of these transition states. Thus in the ovum Plate XXVI. fig. 211, there were present five cells, namely, three large ones, the membranes of each of which seemed about to liquefy and give birth to a progeny of two; and two small ones just brought forth by their now vanished parent cell, which (before its disappearance) had made the fourth of the large cells in the figure. Again, in the germ fig. 215. the number of cells was more than eight, but less than sixteen. Here most of the cells were of equal size; but among them were cells considerably smaller, so that the state seemed comparable to that in fig. 211, though differing from it in the size and number of the cells.

355. The cells are at first elliptical, like the discs of which they are an altered state. Their form is subsequently globular. In the first set (Plate XXVI. figs. 206. 207. *bs*), the dimensions of the containing cavity scarcely admit of this change in form. But there is sometimes observed a tendency to undergo it (fig. 208.), and flattening occurs where the two cells are in contact with one another (fig. 207. and "Second Series," *l. c.*, Plate VIII. fig. 143.)†. That such an alteration in the form (from elliptical to globular) takes place, we obtain an interesting proof on comparing figs. 207. 211 and 212. The cells contained in the twin cells of fig. 207. were elliptical; corresponding cells in fig. 211. had become globular. The two small cells of this figure, which had been liberated, were less elliptical than those still within the parent cells. The outer cells in the germ (*bs*) of fig. 212. corresponded to the elliptic cells in fig. 211, but had undergone the usual change in form. The *inner* cells of the germ (*bs*) in fig. 222. were still elliptical; those in fig. 208. had become nearly globular. And in all later stages of the germ where cells have reached their maturity, the same change in form is found to have taken place (Plate XXVI. fig. 220. Plate XXVII. figs. 223. 224.)‡.

356. A difference in size frequent in the first set of young cells (Plate XXVI. figs. 207. 208.), appears to be the cause of unequal size sometimes observed in the succeeding set (fig. 209.).

† Having in my "Second Series" (*l. c.*, par. 306.) expressed a doubt whether the two objects contained within the ovum in Plate VIII. fig. 143. of that memoir were two yolk-balls, I have now to state my conviction that such was not the case; but that the figure in question exhibits a condition of the germ approaching (but earlier than) that in the present paper, Plate XXVI. fig. 207, the interior of its two cells not having been distinctly seen, with the magnifying power then employed.

‡ The transitory cells which liquefy as the two essential cells advance (par. 349.) do not perhaps, in general, attain the globular form. They often resemble mere discs, the surface of which is membranous, and the most superficial part of the interior of which has passed into fluid. Where, however, such transitory cells escape liquefaction for a while (par. 350.), they become globular.

357. The outer cells of the germ are often more transparent in and near the centre than under their membrane (figs. 210. 216. *bs*). This seems referable to the presence, in and near the centre, of cells which are attaining their greatest size; while under their membrane there is a layer of dark objects. The latter seem to be the foundations of new cells, and probably formed the central part of the interior of larger cells, the membranes of which have disappeared by liquefaction. Subsequently these peripheral dark objects become situated *between* the advancing inner cells, and then we meet with such appearances as those in figs. 218. 221. We thus find that the process described as in operation within the germinal vesicle, and as producing the changes in appearance of the substance surrounding it (par. 351. and Plate XXIV. figs. 191. 193, Plate XXV. figs. 196. 199, Plate XXIV. figs. 188. 189. 179.), manifests itself even in the minutest cells which can be examined. States of the entire ovum are also met with, which, as viewed with a low magnifying power, very much resemble the condition of one of the minute cells in question, and undoubtedly from the same cause; namely, that which has been now described.

358. In each of the cells Plate XXVII. fig. 229. *bs*, an object remained at the periphery; so that each cell with this object resembled the germinal vesicle with that particular state of the germinal spot in Plate XXII. fig. 156. The object in question in the cells fig. 229. corresponded in its situation to that known as the nucleus of the cell, or "cytoblast"; but its free part seemed on the point of being resolved into other cells, the central part presenting a finely granular appearance, and a point in the middle, which in some instances was pellucid, and in others dark. In the cells fig. 230. *bs*, such an object was situated, not at the periphery, but in the centre of each cell. The object here seen, however, corresponded only in *appearance* to the object in fig. 229; for that portion which in fig. 229. seemed about to become resolved into new cells, had in fig. 230. actually formed them, and they filled the parent cell; while the inner portion, which in fig. 229. had a finely granular appearance, now presented in its turn the foundations of new cells.

The rudimental Embryo is the Nucleus of a Cell.

359. A vesicle discovered in my "Second Series" and described as containing "the true germ"† (*l. c.*, Plate VI. fig. 113.), is present in such states as those represented in Plate XXVII. figs. 223. 224, but not easily seen. It is shown in outline in fig. 223, in or near the centre of a group of cells (*bs*); and in fig. 225. is delineated its apparent state, as seen in the group fig. 224. The nucleus, however, was the only part of this cell which could be distinctly seen. Other appearances of this object are represented in figs. 226 and 228. In subsequent conditions the cell has sometimes appeared quite dark (fig. 232.), apparently from globules in its fluid; in other instances it has been found much more transparent (fig. 233.). In fig. 228. the nucleus

† In strictness, this term belongs rather to the objects to which I have applied it in the present memoir, namely, to the twin cells *bs* as well as to their successors *bs*, and therefore to the whole group, or entire mulberry-like object, containing the vesicle above referred to, and including that vesicle itself.

was still at the periphery of the cell. A nucleus resembling that in fig. 226. is seen more highly magnified in fig. 227.

360. This nucleus is the object which in my "Second Series" was traced from a spherical into a linear form; in some stage of which latter state, it appears to correspond to the "primitive trace" of authors on the ovum of the Bird; and, as then shown, it is the rudimental embryo. I then stated it to be the nucleus of a cell (*l. c.*, par. 300.); and from what has been made known in the present memoir in connexion with facts recorded in my last, it appears that the same process by which a nucleus in one instance transforms itself into the embryo, is in operation in another instance where the product does not extend beyond the interior of a minute and transitory cell. Making allowance, indeed, for a difference in form and size, the description given of the mode of production of the one, might be applied to the other†. It was shown (*l. c.*, par. 212.) that in the production of the embryo out of a nucleus, layer after layer of vesicles or cells comes into view in the interior, while layers previously formed are pushed further out; each of the layers being so distinctly circumscribed as to appear almost membranous at its surface. The same membranous appearance we now find to present itself at the surface of the several layers of a nucleus in many situations. See, for instance, the nuclei in the twin cells Plate XXV. figs. 199 and 201. And I have very often found that layers of incipient cells, arising as they do out of a nucleus, appear circumscribed by a membrane. Many instances of this kind have been referred to in former parts of this memoir (par. 349 *Note.*). We saw such membranes forming around the incipient cells within the germinal vesicle (Plate XXIV. fig. 193.), as well as around those of the so-called "yolk" (Plate XXII. figs. 162. 164. 165. 167, Plate XXIII. figs. 172 to 176. *e.*). Farther, in the formation of the embryo, it was shown that the new layers of altered nuclei or cells come into view around a pellucid centre‡; and we now find that a corresponding centre gives origin to similar appearances in every nucleus described in the present memoir§. The altered nuclei or cells, moreover, of which the layers of the embryo are composed||, present an interior denoting a repetition of the same process. The same finely granular ap-

† In my "Second Series" a note was added (*l. c.*, par. 193. *Note.*), admitting the possibility of the nucleus in question disappearing by liquefaction, and of a linear object—corresponding to the "primitive trace" of authors on the ovum of the Bird—arising in its place. The erroneous statement by authors on "cells," that the nucleus is absorbed, misled me into that admission; and I have now to state that I adhere to the opinion originally expressed, that the embryo is the altered nucleus of a cell, and that the "primitive trace" of authors appears to be no other than this same nucleus in a comparatively advanced stage.

‡ It was shown that this mysterious centre is present until it has assumed the form of the cavity, including the *sinus rhomboidalis*, in the central portion of the nervous system.

§ "Second Series," *l. c.*, pars. 197. 209. 212 to 215, Plate VII. figs. 118. 121 A. 121 B. 121 C. 122. 123.

|| *Ibid.* pars. 300. 305. Plate VIII. fig. 149. The "vesicles" represented in this figure, as contained the one within the other, seem to have been the membranes with which the several portions of a nucleus may appear circumscribed, when resolved into cells. We are now also prepared to understand that in my "Second Series," the space between the membrane of an outer and the membrane of an inner "vesicle" should have appeared to be the place of origin of cells; and that they should have been first seen on the outer surface of the inner "vesicle" or "nucleus" (*l. c.*, pars. 303. 304.).

pearance, also, as that preceding the formation of discs or incipient cells in a nucleus, is met with, under the same circumstances, in the nucleus which gives origin to the embryo†.

361. In the ovum Plate XXVII. fig. 232. the germ (*bs*) was in a state assisting to describe the mode in which the membrane *f*, in some instances, becomes lined with cells. The group (*bs*) seemed to consist of two portions, an inner and an outer. The outer portion appeared to be expanding from the inner; that is, it was apparently on its way to the membrane *f*‡.

362. Another mode in which the cells of the mulberry-like group (*bs*) undergo the local change just referred to, is seen in Plate XXVII. fig. 233. Here a process was in operation, destined to bring most of them into contact with the membrane *f*, and at the same time to convey the elliptic cell into a like situation. This process consisted in the gradual formation of a cavity at a certain part of the interior (see the figure). Usually, however, I have seen the changes in question to take place in the manner represented in my last memoir§.

363. During the changes referred to in the two preceding paragraphs, the cells no doubt multiply by the origin of new ones in their interior||, and in proportion to the extent of surface (*f*) which they are required to line. There is every reason for supposing that subsequently also, after reaching this situation, they increase in number by the same means.

364. The facts above recorded will show that I am not enabled to confirm Bischoff's conjecture, referred to in my last memoir: "that in the first place all the yelk-granules are inclosed in two, then in four, then in eight, &c. cells¶." But these facts strengthen the analogy pointed out in that memoir, between the early changes in the ovum of the Mammifera and the divisions previously known to occur in the ovum of Batrachian Reptiles, and some other animals; and it is almost superfluous to add, that I suppose the process in all to be essentially the same‡‡, and that it is in operation in the ova of other animals‡‡. I believe it has hitherto been usual to re-

† "Second Series," par. 197. (Plate VI. figs. 113 to 116. *bb*. Plate VII. fig. 121 C.).

‡ Compare in "Second Series," Plate VI. fig. 110. with fig. 111.; and see in that memoir remarks on the probable mode of origin of the cells lining the membrane *f*, par. 318. *Note*.

§ *L. c.*, Plate VI. figs. 111. 112. 113.

|| It will be recollected that in such a stage two nuclei were on one occasion seen in the same cell ("Second Series," *l. c.*, par. 180. *Note*, par. 318. *Note*).

¶ R. WAGNER's *Lehrbuch*, &c., p. 101.

‡‡ We can now understand the very large size of the germinal vesicle as observed by R. WAGNER in the mature ovarian ovum of the Frog (*Beiträge*, &c., tab. ii. fig. 6. *d*.).

‡‡ Professor RATHKE says, "The yelk of the Crustacea—and also the yelk of other animals—presents appearances, which warrant us in concluding, that at the time when the embryo forms and becomes developed, it [the yelk] is not merely a magazine of inert nutrient material, but rather leads a very powerful life, so that—at all events when the germ first arises—we might compare it to a particular organism, and subsequently to one of the organs of an animal being. For, in the first place, in the ova of *Palemon* and *Crangon*, before a trace of the embryo is visible, the single grains, of which the yelk consists, are seen so to group themselves that they

gard the round white spot or cicatricula on the yelk of the Bird's laid egg as an altered state of the discus vitellinus in the unfecundated ovarian ovum. So far from thinking that such is the case, I venture to believe that the whole substance of the cicatricula in the laid egg of the Bird has its origin within the germinal vesicle in the same manner as in the ovum of Mammalia†, and therefore that the cicatricula in the Bird's laid egg may properly be called the germ‡.

No fixed Relation between the Degree of Development of Ova and their Size, Locality, or Age.

365. In my last memoir it was shown that at early periods the several parts of the ovum do not necessarily keep pace with one another, and that there is no fixed relation between the size of the entire ovum and the degree of development of its most essential part. Of the latter fact, many figures in the present paper afford further proof, and show that the statement is applicable to ova still within the ovary§. The ovarian ovum Plate XXII. fig. 162, measured $\frac{1}{11}'''$, though it had not undergone fecundation||. That in Plate XXIII. fig. 172, was certainly fecundated, but it measured only $\frac{1}{15}'''$. The ovum Plate XXV. fig. 196, measured $\frac{1}{8}'''$, but was less advanced in the essential part than that in fig. 198, which had less than half its diameter. Several other instances of this kind will be found on comparing the figures. The large size, however, which ova in some instances attain without the germ being proportionably developed, is referable mainly to the quantity of fluid imbibed by the chorion; for before the formation of this membrane the irregularity in question is not so great. This will be seen on reference to the Table, par. 428, in which the measurements of the chorion and membrane *f* in many ova have been recorded¶.

366. There are two other ways in which irregularity occurs, namely, in regard to time and place. The ovum Plate XXV. fig. 196, was taken from a Rabbit killed sixty-six hours *post coitum*; that in fig. 198, though more advanced, was only $5\frac{1}{2}$ hours old, that is one-twelfth the age. And if these two ova be compared with regard to their local situation, the difference will be found equally remarkable. The older and larger, but less developed ovum, fig. 196, was found in the uterus; the younger and smaller but more developed ovum, fig. 198, was still within the ovary. These, however, are

enter entirely into the formation of single accumulations, which through furrows and a pellucid substance become separated from one another, but subsequently again become confluent and coalesce." (Zur Morphologie Reisebemerken aus Taurien, p. 102.)

† The principal of the changes producing it having, perhaps, taken place before the ovum left the ovary.

‡ See also "Second Series," par. 318. and Notes.

§ As the ova for the most part are shown as magnified the same number of diameters, the fact here referred to may be easily attested by inspection of the Plates.

|| It was taken indeed from a Rabbit which had not had connexion with the male.

¶ If the figures in Plate XXVII. be compared, it will be seen, however, that fig. 234, an ovum among the most developed in its essential part, has a very small membrane *f*.

rare instances of deviation, and by far the most remarkable which I have met with in stages so very early.

367. There is yet another species of irregularity. Ova found with the one in Plate XXV. fig. 196, just referred to, were duly advanced in their development, though the less developed ovum had kept pace with them in its passage through the oviduct†.

368. Vesicles such as those mentioned in my last paper, *l. c.*, par. 227, as having been found in the Fallopian tube, I am now enabled to state are of frequent occurrence, and often measure $\frac{1}{8}'''$ to $\frac{1}{4}'''$. These vesicles generally contain only a transparent fluid: granules or cells, such as those in Plate VIII. fig. 136. of my "Second Series," being rarely seen. The resemblance between the vesicles in question and the thick transparent membrane (*f*) of the ovum, is too remarkable not to induce the belief that these objects are identical; and the vesicles occur so frequently, that I venture to regard them as the remains of ova escaping from the ovary without fecundation. Should others—on finding such vesicles—be of this opinion, physiologists may be thus assisted in determining a question on which they are not agreed.

The Chorion formed of Cells arising in the Oviduct.

369. The observations made known in my "Second Series" on the mode, the period, and the place of origin of the chorion, I now confirm. That the thin membrane there described, as rising from the thick transparent membrane *f*, and imbibing fluid, is really the incipient chorion, was shown by tracing it from stage to stage up to the period when villi form upon it. There remained, however, two questions undecided, namely, whether the chorion is formed of cells; and if so, whether the cells are those of the so-called "disc" brought with the ovum from the ovary.

370. I have now to state that the chorion *is* formed of cells; and that these cells are *not* those of the "disc" brought with the ovum from the ovary.

371. It has been already mentioned (par. 345.) that after the fecundation of the ovum, the cells of the tunica granulosa are found enlarged, club-shaped, in contact with the membrane *f* by their pointed extremities alone, and as it were radiating from the ovum (Plate XXV. fig. 195. *g*¹). In this state of its surrounding cells—and accompanied by the retinacula, more or less advanced in liquefaction—the ovum leaves the ovary.

372. In Plate XXIV. fig. 185. is represented an ovum of 14 hours, found in the Fallopian tube at its middle part. The membrane *f* was invested by cells which together seemed to form a sort of mosaic work. On examining them closely, however, these cells were found at many parts to have coalesced, and this was especially the case on the left side (see the figure). Their appearance was very different from that of the cells surrounding the ovarian ovum; the former being much more minute, and having

† In this instance four ova were found at the uterine extremity of the Fallopian tube, and three in the beginning of the uterus; one of the latter having been that in Plate XXV. fig. 196.

a very different interior and form. Some of these cells are shown more highly magnified in Plate XXVIII. fig. 253. *a.*; which presents also a portion of the membrane *f.* Some of the same cells (fig. 253. *β.*) were observed lying near the ovum. These cells had sent out processes, which at *a* were seen to have become interlaced, and in part to have coalesced. A central pellucid space, present in each of these cells, and originally round (*β.*), had changed its form in many of the cells *a.*, and seemed to be following the direction of the interlacing processes. These cells having gradually collected around the thick transparent membrane (*f.*), and interlaced, by coalescing form the incipient chorion.

373. In fig. 252. is seen a state rather earlier than that in fig. 253†. Here (*α*) the pellucid centres were still round, and the interlacing arms or processes of the cells had scarcely begun to coalesce. At *β* in this figure are some of these cells which had a more superficial situation on the same ovum. They were not so close together as the preceding (*α*), to which they had probably been added. It appears indeed to be by additions of cells, thus made externally, that the chorion thickens (see Plate XXVI. figs. 211. 212, Plate XXVII. figs. 229 to 234. *cho.*), and it would not be easy to determine when these additions cease, or indeed whether they cease at all before the addition of villous tufts, which I am very much disposed to think are formed by the same kind of cells. These cells will be particularly referred to in a future paper‡.

374. In Plate XXIV. figs. 186. 187 and 189. the incipient chorion is seen to have been just beginning to imbibe transparent fluid, and to rise from the membrane *f.* Whether the so-called "disc" brought with the ovum from the ovary contributes to supply this fluid, I do not know; but when the chorion is in an incipient state, many of the cells of the "disc" are sometimes found lying around it; and in other instances there is in the same situation, a transparent fluid, which may possibly have arisen from the liquefaction of those ovarian cells.

Application of some of the foregoing Facts to the Physiology of Cells.

375. Existing views regarding "cells" have been already briefly stated (par. 324). The Appendix contains them more in detail.

376. Presuming that what is known regarding cells warrants the conclusion that they have essentially the same structure in animals and plants, I offer the following remarks as applicable equally to the animal and vegetable cell§. And as researches have hitherto related chiefly to the cells of plants, I shall refer for the most part to what has been published respecting these.

377. That I have found the nucleus at the surface of its cell, is shown by figures in the present and in the two preceding memoirs. As this, however, rarely continues to be its situation at the period I have investigated, it may be proper to compare my

† Fig. 252. was taken from an ovum of 11 hours; fig. 253. from an ovum of 14 hours.

‡ I think it very probable however that there is an origin of new cells within those already coalescing.

§ Except in those instances where reference is made to structures belonging exclusively to plants.

observations with those of others, on the appearance and the destination of this very important structure, when it does not continue at the surface of the cell.

378. The first question is,—which of the objects figured by me in the present "Series," correspond to the nucleus of authors? No one will doubt that the object eccentric in one of the twin cells Plate XXV. fig. 203, is to be considered as so corresponding; an object resembling the "corpuscle" or nucleolus of SCHLEIDEN, being also present in its centre. Nor is it to be supposed that any question will arise as to the identity of that nucleus with the central nuclei in, for instance, the twin cells *bs* of Plate XXIV. fig. 191. It is obvious that they differed only in local situation; the nucleus in fig. 191. having passed to the centre of its cell. Thus far then my observations accord with existing views; but, I am compelled to say, not any farther.

379. SCHLEIDEN remarks, that in its original position the nucleus (or "cytoblast") "accompanies the cell which it has formed through the whole vital process, if it be not (as in cells destined for higher development) dissolved and absorbed—cast off as a useless member. This disappearance of the nucleus takes place either *in situ*, or it is first thrown into the centre of the cell†."

380. Let us now trace the appearances presented by the nucleus, according to my own observations, after it has passed to the centre of the cell. In the ovum Plate XXIV. fig. 191, as seen highly magnified (fig. 192.), the outer portion of the nucleus seemed to consist of the foundations of new cells. The corresponding part in Plate XXV. fig. 199. had enlarged, and an inner part come into view. Fig. 200. presents an ovum in which the twin cells had become filled with concentric layers of objects, which on close examination were found to be no other than the foundations of new cells. From the presence of such objects in the nucleus Plate XXIV. fig. 187, and from the condition of the latter in fig. 193, and Plate XXV. figs. 194. 196, it will perhaps be admitted that, in these instances, the place of the original nucleus of the cell, or "cytoblast," was occupied by the foundations of other cells, which, in some cases, had been pushed further out by fresh sets arising in the interior.

381. Now in this "Third Series" of researches, I have not met with any nucleus in which the same succession of appearances was not either directly witnessed, or to be inferred. The germinal spot—obviously a nucleus—was particularly traced (pars. 327. 328.), and the germinal vesicle found to fill with more or less incipient cells in a manner essentially the same as that just described. The substance surrounding the germinal vesicle, in the ovum Plate XXII. fig. 156, consisted of elliptical and flattened objects, having an interior not materially differing from that above referred to; and a similar condition of that substance will be found in many other figures.

382. But further, on closely examining the discs or foundations of cells successively coming into view in the manner above mentioned, we find in their interior a repetition of the same appearances—the foundations of yet other cells. This I have attempted to illustrate in outline in Plate XXIII. fig. 177, which I beg to state represents nothing theoretical,—nothing more than I have actually seen. For instance,

† Appendix, par. 425.

the interior of each of the larger objects in the germinal vesicle Plate XXIII. fig. 169. c, presented an appearance fully warranting the section fig. 177; though it was not possible to represent this appearance in that small figure. The section fig. 177. is, in fact, a delineation of one of the objects in the substance surrounding the germinal vesicle in an ovarian ovum of $8\frac{1}{4}$ hours. And in no object of the kind sufficiently advanced, and the interior of which the eye could reach, have I failed to find traces of a structure essentially the same (see Plate XXV. figs. 200. 201.).

383. Only a first and second order of discs or incipient cells have been exhibited in that section (Plate XXIII. fig. 177.), because I wish to figure nothing more than has been actually seen. But my experience of these objects is such as to warrant the belief that more orders might have been introduced. Indeed it is not possible to say where the process ends, except in liquefaction.

384. In following out this process we have thus seen the nucleus, and especially its centre, to be the seat of changes which were not to have been expected from the existing doctrine, that the disappearing nucleus has performed its entire office by giving origin at its surface to the membrane of a single cell. It is the mysterious centre of a nucleus—the germinal spot—which is the point of fecundation, and the place of origin of two cells constituting the foundation of the new being. The germinal vesicle is the parent cell, which, having given origin to two cells, disappears, each of its successors giving origin to other two,—and so on. Perpetuation, however, at this period consists, not merely in the origin of cells in cells, but as we have seen, in the origin of cells in the pellucid centres of the nuclei of cells†.

385. The quotations in the Appendix I think will be found to contain internal evidence of SCHLEIDEN having seen the nucleus undergoing changes such as those above described; but he was far from recognizing them. This author states that the nuclei—or, as he calls them, the “cytoblasts”—“grow and diminish in their size.” He found his nucleolus to present various appearances. In well-developed “cytoblasts” it resembled “a thick ring or a thick-walled hollow globule;” in those less developed, there was seen “only the outer sharp contour of this ring, and in its middle an opaque point;” in “cytoblasts” still smaller, “only a sharply circumscribed spot;” in others, no more than “a remarkable, minute, opaque point;” and in the smallest and most transitory, “it was not to be detected.” He observed the diameter of the nucleolus to vary “from half that of the cytoblast to points immeasurably small.” Sometimes the nucleolus appeared to him to be “more opaque, at others more pellucid than the rest of the substance of the cytoblast.”—In connexion with these observations of

† Dr. HENLE has described the “nucleus” of pus and mucus globules as becoming cleft or divided by acetic acid into roundish or oval parts, each having a depression in the middle. (VALENTIN'S Repertorium, 1839, II. pp. 224, 225.) Compare with the minutest discs in Plate XXII. fig. 162. I think, however, that acetic acid shows rather the *existing state* of the object in question; this being in pus the *eccentric nucleolus* of a cell. Besides, the present memoir is full of facts demonstrating that division is a natural mode of reproduction of the nucleus and nucleolus, and apparently common to these objects everywhere. (All the figures which accompany this paper represent objects as seen without the addition of any substance whatever. They were viewed lying either in fluid from the Graafian vesicle, or in mucus from the oviduct.)

SCHLEIDEN, I refer to what has been above stated regarding the changes in appearance presented by the nucleus, from the resolution of its outer portion into cells, and the continual origin in the interior of the foundations of new cells, and hence the varying size of the central pellucid cavity (par. 327.); believing that the apparent growth and diminution, and the final "absorption of the nucleus," supposed by SCHLEIDEN, as well as the nature of his nucleolus, are to be thus explained. If so, however, it will be seen that the formation of the nucleus precedes that of the nucleolus, instead of being consequent upon it, as supposed by SCHLEIDEN†. There seems, in fact, to arise at the surface of the nucleus a succession of objects, each of which, in turn, is a nucleolus: and this after the formation of the cell. More particularly considered, the process seems to be as follows. The progressive resolution of the germinal spot into layers of incipient cells, has shown us that the formation of each successive layer is preceded by a finely granular appearance, the latter surrounding a pellucid fluid‡. It seems to be in this finely granular part that the discs or incipient cells come into view (Plate XXIV. fig. 192.). On the enlargement of the latter, an inner part, previously pellucid, is found to have become finely granular; but this also surrounds a pellucid central fluid, and so on. It would thus seem that the central pellucid fluid becomes finely granular. The ever-varying appearance called the nucleolus, I apprehend to arise from the refraction of light; the degree of which, and the particular situation in which it occurs, depend chiefly on two circumstances, namely, the condition of the granular substance by which the pellucid fluid is immediately surrounded, and the quantity of this fluid which is present. SCHLEIDEN considered the presence of two (or more) nucleoli as exceptions. I am disposed to regard them as constant at a certain period; and as denoting the origin of the two (or more) essential cells.

386. The discoveries of my friend Professor SCHWANN§—on the correspondence in the elementary structure of Animals and Plants—were referred to on a former occasion||, as being among the most important that had ever resulted from microscopic observation¶. That excellent observer, however, did not attempt to conceal the fact, that he had met with certain difficulties, and was obliged to leave them for future explanation. For instance, with reference to the objects he considered hollow and pellucid nuclei,—differing as he found these to do in their appearance from the ordinary "cytoblast,"—he remarks††: "Observation on the transition-steps from the characteristic form of the nuclei of cells, must furnish the required explanation of

† This view of SCHLEIDEN on the mode of origin of the nucleus of the vegetable cell has been adopted by authors on the cells of animal tissues. VALENTIN, having given an abstract of the work of SCHWANN on Cells, remarks, "Nach diesen, so wie nach den Erfahrungen von J. MÜLLER, HENLE und dem Ref. stellt es sich also als Grundschemata der ersten Bildung der Gewebtheile in der Thierwelt heraus, dass in einer Flüssigkeit, cytoblastema, sich Körnchen, Nucleoli niederschlagen und dass um diese sich grössere feinere Körper, Nuclei bilden."—Repertorium, 1839, II. p. 284.

‡ See also the rudimental embryo, "Second Series," I. c., Plate VII. fig. 121 B, 121 C.

§ Mikroskopische Untersuchungen, &c.

|| "Second Series," I. c., par. 290.

¶ Those discoveries have also been mentioned in the present memoir (par. 324.). †† L. c., p. 211.

these cell-like nuclei. But a decision of the question is obtainable only through demonstration that the whole relation of such a cell-like nucleus is to a cell, the same as that of the ordinary nuclei of cells, namely, it must be shown that such a nucleus arises before the cell, that the cell forms itself as a layer around the nucleus, and that finally the nucleus is absorbed in the cell." Again, referring to the experience of SCHLEIDEN, that in plants it is nearly if not quite universal that new cells arise within previously existing cells, SCHWANN remarks†, "In animals—the formation of cells in cells is the rarer case, but happens in so far as that a three to four-fold generation may successively form in one cell.—In cartilage by far the most cells arise in the cytotblastema external to the cells already present." I shall think myself fortunate if any of the observations recorded in this or the preceding memoir, should contribute towards the solution of these and other questions.

387. In my "Second Series," after having applied the term "nucleus" to certain germinal vesicle-like objects observed in the cells of various parts‡, I suggested that perhaps the granules or globules surrounding those objects might, rather, have been the remains of a nucleus. I have now to state, that facts observed in the present "Series" confirm the view then taken. Thus the germinal vesicle-like objects in Plate XXVIII. fig. 245. α and β certainly correspond to those just referred to; and they are situated *in* that which had been the nucleus of the cell.

388. Now should it prove that I am right in considering the germinal vesicle-like objects of my "Second Series," and those in Plate XXVIII. fig. 245. of this memoir, as corresponding to the pellucid cavity in a nucleus, it will be obvious that the relation of such an object to a cell, is not "the same as that of the ordinary nuclei of cells." And since I cannot but regard those germinal vesicle-like objects as corresponding also to some of the "hollow," "pellucid," and "cell-like nuclei" of SCHWANN, I venture to believe that some light may have thus been thrown upon one of the difficulties left by that observer for future explanation.

389. From these remarks, however, it will be seen that I cannot adopt the opinion of SCHWANN, that the pellucid object in epithelium-cells is a "cytoblast." And facts made known in the foregoing pages show that the germinal vesicle itself cannot be so considered.

390. SCHWANN conjectures that the contents of the cell ("zellen-inhalt") may contribute to the secondary deposits observed to take place in plants on the inner surface of the membrane of the cell; and which, according to VALENTIN, always occur in spiral or other lines. SCHWANN had not observed such secondary deposits in animal cells; yet from the correspondence he has pointed out between elementary structures in the two kingdoms, I think the following may perhaps be worthy of consideration. SCHLEIDEN remarks§, "The formation of secondary deposits on the inner sur-

† *L. c.*, p. 204.

‡ *L. c.*, Plate VI. fig. 110, Plate VII. figs. 120. 121, Plate VIII. figs. 129. 130. 132. 150.

§ *L. c.*, p. 146.

face of the cell-wall does not commence, so far as I could observe, until after the absorption of the cytoblast." Now I would suggest that the "cytoblast," instead of being absorbed, resolves itself into discs or cells, thus furnishing in the first place the contents of the cell ("zellen-inhalt"), and, through these, the deposits in question. The same observer states "the interesting result, that the [spiral] fibres never form free, but always in the interior of cells;" and I would offer the same suggestion with respect to these.

391. SCHWANN† describes young cells in certain situations as at first perfectly transparent. "Gradually, however," says he, "they acquire a granular, yellowish appearance; and it is remarkable that this yellowish precipitate generally or always forms first around the nucleus." Does not such "precipitate" consist of the substance into which the free portion of the nucleus becomes resolved? The same observer states‡ that "In the gill-cartilage of the Tadpole many cells present a minute nucleus having lacerated contours, which is perhaps the cytoblast of these cells undergoing absorption." I venture to believe, that it may be the nucleus resolving itself into cells.

392. SCHWANN§ observed nuclei in some instances to enlarge, as SCHLEIDEN had done in plants. Compare in the present memoir the size and condition of the nuclei in the twin cells (*bs*) of Plate XXIV. fig. 191. with those in Plate XXV. figs. 199. 201.

393. SCHWANN has shown that in cartilage, cells occur in groups||. With regard to these groups I would remark, that their appearance very much resembles that which would be presented by several generations of the twin cells of the germ (described in this memoir) inclosed the one within the other. And the resemblance suggests to me the idea that both result from the same process. SCHWANN offers as possible the following explanation. "These groups perhaps arise from two to four cells having formed in a parent cell, in which case each half of the cell-wall must consist of two layers, one of which corresponds to the wall of the parent cell, the other to the wall of the secondary cell; so that thus each partition wall of two groups must consist of four layers" (*l. c.*, p. 22.). Subsequently, however (pp. 113. 114.), he expresses doubt as to the sufficiency of such an explanation. We saw, in tracing the cells which successively enter into the formation of the germ, that very many of those into which the nucleus becomes resolved, disappear by liquefaction. Is it not possible—supposing cartilage to be formed by a like process—that, instead of liquefying, the supernumerary cells contribute to the thickening of the walls of the parent cell? We have seen too (pars. 351 and 357.) that minute cells (apparently from the interior of liquefied parent cells) become introduced between enlarging cells (Plate XXIII. fig. 179, Plate XXIV. figs. 188. 189.); and also that, however minute, cells seem to give origin in their interior to other cells. Now if, instead of disappearing by liquefaction, the minute cells so introducing themselves between larger ones were

† *L. c.*, p. 24.‡ *L. c.*, p. 26.§ *L. c.*, pp. 27, 28.|| *L. c.*, tab. i. figs. 8, 9.

to continue, and give origin to others in their interior, the resulting substance might increase to an indefinite amount. May not this be the mode producing the intercellular—that is, the real—substance of cartilage? I am the more disposed to think this possible, from the fact that in the gill-cartilage of fishes, SCHWANN found the intercellular substance to consist of the closely aggregated walls of cells.

394. Though ignorant of the precise nature of the process by which what were termed the divisions and subdivisions in the ovum were produced, I showed in my last memoir†, that it consisted in the origin of cells in cells; and suggested that it might admit of being extended to explain the increase of other cells. This opinion has been strengthened by the later observations,—which have enabled me in the present paper to communicate particularly the nature of the process,—as well as by the appearance of various cells incidentally observed. For instance, it has been very common to find the so-called epithelium-cells of the oviduct, filled with cells. Several of the varieties of these, some of them carrying cilia, are represented in Plate XXVIII. figs. 248 to 251. The cells of the so-called “disc” also (my tunica granulosa and retinacula), exhibit cells in their interior; and it is deserving of notice that in some instances the contained cells are only two in number (Plate XXVIII. figs. 245. γ, 247.). But on a former occasion we saw that the cells of which the entire embryo at certain periods is composed, are filled apparently with the foundations of other cells‡.

395. The experience of Professor SCHWANN, however, does not accord with these observations. He remarks§, “I have above mentioned an observation according to which, in the Tadpole, a young epithelium-cell formed within another. This, however, is a very rare case, and in all the Vertebrata most epithelium-cells decidedly do not form as cells in cells, but in a minimum of cytotblastema exuding from the cutis.” And with reference to the experience of SCHLEIDEN, that in plants it is nearly or quite universal that new cells arise nowhere but in previously existing cells, SCHWANN remarks||, “In animals—the formation of cells in cells is the rarer case, but happens in so far as that a three to four-fold generation may successively form in one cell.—In cartilage by far the most cells arise in the cytotblastema [intercellular substance, see par. 393.] external to the cells already present¶.”

† *L. c.*, par. 314 to 317.

‡ “Second Series,” *l. c.*, Plate VII. figs. 121 to 123, Plate VIII. fig. 150.

§ *L. c.*, p. 87.

|| *L. c.*, p. 204.

¶ Judging from the delineations given by authors, I am more and more disposed to think the remarkable process of early development described in this memoir is in operation at all periods, and this for the production of morbid as well as healthy tissues. The process in question, as we have seen, consists first, in the foundations of young cells arising apparently in no other way than by divisions of the nucleus of a mother-cell, and secondly in the complete evolution of only two young cells, out of myriads which form. (The number continuing may in some instances be several; these two occupying a central situation.) That this process is not peculiar to the period which I have investigated, we have evidence I think in SCHWANN's delineations of the cells of cartilage (*l. c.*, tab. I. figs. 8. 9.) before referred to; and in figures by VALENTIN of ganglion-globules (Ueber die Scheiden der Ganglien-Kugeln und deren Fortsetzungen, in MÜLLER's Archiv, 1839, ii. p. 139. taf. VI. fig. 1. a, b, c.). And that it is not peculiar to healthy structures, is shown, I think, in some of the delineations given by MÜLLER of morbid growths. (Ueber den feineren Bau und die Formen der Krankhaften

396. The remarkable process described in this memoir as giving origin to the new being in the mammiferous ovum (as already said), is no doubt universal. I think that there is evidence of its operation in the ova of Batrachian Reptiles, some osseous Fishes, and certain of the Mollusca†; though the explanations given of these have been of a very different character‡.

Comparison of the Germs of Animals and Plants.

397. SCHLEIDEN's description of the process by which the early changes in the vegetable germ ("embryo") are produced, is strikingly analogous in *some* respects to the one I have given of the incipient growth of the germ in the mammiferous ovum. This excellent observer, on the subject of the formation of cells in cells, states that the process "presents itself in the embryonal extremity of the pollen-tube, that is, in a very much elongated cell.***After the first cells, usually few in number, have formed, they rapidly distend so much as to fill the pollen-tube, and the latter soon becomes no longer visible as the old surrounding membrane. But immediately there arise in the interior of each of these cells several cytoblasts, which produce new cells, through the rapid distention of which the parent cells likewise cease to be visible and are absorbed. The same process is repeated, and so on. But as the newly arisen cells have less and less space for distention, and hence become more and more minute, the previous transparency ceases, through the constant generation of new cytoblasts taking place in the interior, and through the tissue becoming more and more compressed. From that period to the perfect completion of the embryo, the certainly logical inference leads us to the result, that the processes thus introduced continue the same, since no new force comes into action, which might determine us to admit a sudden change—more especially as we soon again meet with the same manifestation of vegetative power§." SCHLEIDEN then proceeds to show that the same process, by which the embryo arises, continues after the formation of the plant, and that cells never originate otherwise than in previously-formed cells. He says, in briefly summing up, "a simple cell—the pollen-tube—is its first foundation. In this arise cells; in them are developed other cells, and so on through life."

398. It will be seen that while it bears a general resemblance which is very striking, the description now quoted from Dr. SCHLEIDEN of the process to which the changes in the vegetable germ are referable, differs from that which I have given of

Geschwülste, I. Lief. Berlin, 1838; an excellent translation of which into English has been given by Dr. West.) I would refer particularly to the following figures of cells delineated by Professor MÜLLER; namely (West's translation) Plate II. fig. 14. (Carcinoma Mammæ simplex),—Plate III. fig. 2. (C. reticulare),—fig. 3^b. (C. alveolare),—fig. v. (Sarcoma of the Brain),—Plate IV. fig. 14. (Osteo-sarcoma),—Plate V. fig. 4. (Enchondroma).

† For instance, *Planorbis cornue* (JACQUEMIN, Nova Acta Acad. Cæs. Leopold. Nat. Cur. 1838, p. 637.).

‡ The last explanation is that of Professor BISCHOFF, quoted in my "Second Series" (par. 307. Note.).

§ L. c., pp. 162. 163.

incipient growth in the germ of the mammiferous ovum, in the following respects; namely, SCHLEIDEN does not state that the nucleus performs any part in the formation of new cells; or that only two—of many cells arising—succeed the parent cell†.

399. Figs. 235 to 243 Plate XXVIII, copied from delineations by SCHLEIDEN‡, represent the vegetable "embryo" (germ) in very early stages. On comparing them with certain states of the mammiferous germ, I find it difficult to believe that they do not result from essentially the same process§. Thus the upper part of fig. 237. admits of comparison with the essential portion of the ovum in several figures of Plate XXIII.; the upper part of fig. 238. with *bs* in Plate XXVI. fig. 206; the upper part of fig. 239. with *bs* in Plate XXVI. fig. 212; the upper part of fig. 240. with *bs* in Plate XXVI. fig. 220; the upper part of figs. 241. 242. with Plate XXVII. figs. 233 and 234. In the last-mentioned figures, perhaps the "*punctum vegetationis*" of WOLFF (figs. 241. 242. *b*) is represented in the mammiferous ovum (Plate XXVII. figs. 233. 234.) by the rudimental embryo (*bb*), and the incipient cotyledons by the remainder of the germ.

400. Thus the germ of certain plants passes through states so much resembling those occurring in the germ of mammiferous animals, that it is not easy to consider them as resulting either from a different fundamental form, or from a process of development which, even in its details, is not the same as what has been above described; the fundamental form in question, in Mammalia, and therefore it may be presumed in Man himself, being that which is permanent in the simplest plants,—the single isolated cell||.

Recapitulation.

401. The almost universal supposition, that the Purkinjean or germinal vesicle is the essential portion of the ovum, has been realized in these investigations; but in a manner not anticipated by any of the numerous conjectures which have been published. The germinal vesicle becomes filled with cells, and these again become filled with the foundations of other cells; so that the vesicle is thus rendered almost opaque. The mode in which this change takes place is the following, and it is one which, if confirmed by future observation, must modify the views recently advanced on the mode of origin, the nature, the properties, and the destination of the nucleus in the physiology of cells. It is known that the germinal spot presents, in some instances, a dark point in its centre. Such a point is invariably present at a certain period; it enlarges, and is then found to contain a cavity filled with fluid, which is exceedingly

† It is deserving of notice, however, that in reference to *Marchantia polymorpha* SCHLEIDEN states, "Of the cell-germs [cytoblasts] found in the spores, few only—at the most two to four—serve for the formation of cells; the others soon becoming covered with chlorophyll, and thus withdrawn from the vital process." (*l. c.* p. 137.)

‡ *L. c.*, tab. iii. fig. 17. WIEGMANN's Archiv. 1837, tab. vii. figs. 13 to 15, and figs. 6. 7. 16. 17. 8.

§ See also a remark in my "Second Series," *l. c.*, par. 318. Note.

|| See remarks in my "Second Series," *l. c.*, par. 318. Note, par. 312.

pellucid. The free portion of the spot resolves itself into cells; and the foundations of other cells come into view in its interior, arranged in layers around the central cavity; the layers being pushed forth by the continual origin of new cells in the interior. The latter commence as dark globules in the pellucid fluid of the central cavity. Every other nucleus met with in these researches has seemed to be the seat of changes essentially the same. The appearance of the central portion of the nucleus is, from the above process, continually varying; and the nature of the nucleolus of SCHLEIDEN may perhaps be thus explained. The germinal vesicle, enlarged and flattened, becomes filled with the objects arising from the changes in its spot; and the interior of each of the objects filling it, into which the eye can penetrate, presents a repetition of the process above described. The central portion of the altered spot, with its pellucid cavity, remains at that part of the germinal vesicle which is directed towards the surface of the ovum, and towards the surface of the ovary. At the corresponding part, the thick transparent membrane of the ovum in some instances appears to have become attenuated, in others also cleft. Subsequently, the central portion of the altered spot passes to the centre of the germinal vesicle; the germinal vesicle, regaining its spherical form, returns to the centre of the ovum, and a fissure in the thick transparent membrane is no longer seen. From these successive changes it may be inferred that fecundation has taken place; and this by the introduction of some substance into the germinal vesicle from the exterior of the ovary. It may also be inferred, that the central portion of the altered germinal spot is the point of fecundation. In further proof that such really is the case, there arise at this part two cells, which constitute the foundation of the new being. These two cells enlarge, and imbibe the fluid of those around them, which are at first pushed further out by the two central cells, and subsequently disappear by liquefaction. The contents of the germinal vesicle thus enter into the formation of two cells. The membrane of the germinal vesicle then disappears by liquefaction.

402. Each of the succeeding twin cells presents a nucleus, which, having first passed to the centre of its cell, resolves itself into cells in the manner above described. By this means the twin cells, in their turn, become filled with other cells. Only two of these in each twin cell being destined to continue, the others, as well as the membrane of each parent cell, disappear by liquefaction, when four cells remain. These four produce eight, and so on, until the germ consists of a mulberry-like object, the cells of which do not admit of being counted. Nor does the mode of propagation continue the same with reference to number only. The process inherited from the germinal vesicle by its twin offspring, reappears in the descendants of these. Every cell, whatever its minuteness, if its interior can be discerned, is found filled with the foundations of new cells, into which its nucleus has been resolved. Together with a doubling of the number of the cells, there occurs also a diminution of their size. The cells are at first elliptical, and become globular.

403. The above mode of augmentation, namely the origin of cells in cells, appears

by no means to be limited to the period in question. Thus it is very common to meet with several varieties of epithelium-cells in the oviduct (including those which carry cilia) filled with cells; but the whole embryo at a subsequent period is composed of cells filled with the foundations of other cells.

404. In the Second Series of these researches, it was shown that the mulberry-like object above mentioned, is found to contain a cell larger than the rest, elliptical in form, and having in its centre a thick-walled hollow sphere, which is the nucleus of this cell. It was farther shown that this nucleus is the rudimental embryo. From what has been just stated, it appears, that the same process, by which a nucleus in one instance transforms itself into the embryo, is in operation in another instance, where the product does not extend beyond the interior of a minute and transitory cell. Making allowance, indeed, for a difference in form and size, the description given of the one might be applied to the other. It was shown in the Second Series, that in the production of the embryo out of a nucleus, layer after layer of cells comes into view in the interior, while layers previously formed are pushed further out; each of the layers being so distinctly circumscribed as to appear almost membranous at its surface. The same membranous appearance presents itself at the surface of the several layers of a nucleus in many situations. Farther, in the formation of the embryo, a pellucid centre is the point around which new layers of cells continually come into view; a centre corresponding to that giving origin to similar appearances in every nucleus described in the present memoir. It was shown that in the embryo this mysterious centre is present until it has assumed the form of the cavity, including the sinus rhomboidalis, in the central portion of the nervous system.

405. The process above described as giving origin to the new being in the mammiferous ovum, is no doubt universal. There appears to be evidence of its occurrence in the ova of Batrachian Reptiles, some osseous Fishes, and certain of the Mollusca; though the explanation given of these has been of a very different character. It has hitherto been usual to regard the round white spot, or cicatricula, on the yolk of the Bird's laid egg, as an altered state of the discus vitellinus in the unfecundated ovarian ovum. So far from such being the case, it is probable that the whole substance of the cicatricula in the laid egg has its origin within the germinal vesicle, in the same manner as in the ovum of Mammalia.

406. There is no fixed relation between the degree of development of ova, and their size, locality, or age. The variation with regard to size is referable chiefly to a difference in the quantity of fluid imbibed in different instances by the incipient chorion. Vesicles filled with transparent fluid are frequently met with in the Fallopian tube, very much resembling the thick transparent membrane of the ovarian ovum. These vesicles are probably unimpregnated ova, in the course of being absorbed. The so-called "yolk" in the more or less mature ovarian ovum, consists of nuclei in the transition state and exhibiting the compound structure above described. The mass of these becomes circumscribed by a proper membrane. They and their membrane

subsequently disappear by liquefaction, and are succeeded by a new set, arising in the interior, and likewise becoming circumscribed by a proper membrane, and so on. This explains why some observers have never seen a membrane in this situation. After the fecundation of the ovum, the cells of the tunica granulosa, that is, part of the so-called "disc," are found to have become club-shaped, greatly elongated, filled in some instances with cells, and connected with the thick transparent membrane by their pointed extremities alone.

407. That the thin membrane described in the Second Series of these researches as rising from the thick transparent membrane in the Fallopian tube, and imbibing fluid, is really the incipient chorion, was then shown by tracing it from stage to stage, up to the period when villi form upon it. There remained, however, two questions undecided; viz. whether the chorion is formed of cells, and if so, whether the cells are those of the so-called "disc," brought by the ovum from the ovary. It may now be stated that the chorion *is* formed of cells, which gradually collect around the thick transparent membrane, and coalesce; and that the cells in question are *not* those of the "disc" brought with the ovum from the ovary. The cells which give origin to the chorion are to be more particularly described in a future paper.

408. The existing view, namely, that a nucleus, when it leaves the membrane of its cell, simply disappears by liquefaction, is inapplicable to any nucleus observed in the course of these investigations. The nucleus resolves itself into incipient cells in the manner above described. In tracing this process, it appears that the nucleus, and especially its central pellucid cavity, is the seat of changes which were not to have been expected from the recently advanced doctrine, that the disappearing nucleus has performed its entire office by giving origin at its surface to the membrane of a single cell. It is the mysterious centre of a nucleus which is the point of fecundation; and the place of origin of two cells constituting the foundation of the new being. The germinal vesicle, as already stated, is the parent cell, which, having given origin to two cells, disappears, each of its successors giving origin to other two, and so on. Perpetuation, however, at this period, consists, not merely in the origin of cells in cells, but in the origin of cells in the pellucid centres of the nuclei of cells.

409. Neither the germinal vesicle, nor the pellucid object in the epithelium-cell, is a "cytoblast." The cells into which the nucleus becomes resolved, may perhaps enter into the formation of secondary deposits—for instance, spiral fibres; and they may contribute to the thickening which takes place, in some instances, in the cell-membrane.

410. The germ of certain plants passes through states so much resembling those occurring in the germ of mammiferous animals, that it is not easy to consider them as resulting either from a different fundamental form, or from a process of development which, even in its details, is not the same as what has been above described; the fundamental form in question in Mammalia, and therefore it may be presumed in Man himself, being that which is permanent in the simplest plants,—the single isolated cell.

APPENDIX.

Statements and Conjectures of Physiologists on the Nature, Office, and Destination of the Purkinjean or Germinal Vesicle (see par. 323, &c.).

411. The discoverer of this vesicle was PURKINJE†, whose name physiologists have justly associated with it. The discovery was made in the ovarian ovum of the Bird. Never finding it in ova which had entered the oviduct, PURKINJE supposed the vesicle to burst, and this from pressure of the oviduct. He supposed it to originate the colluquamentum. Subsequently he expressed the following opinion: "During the generative act and the impregnation following, it bursts and pours its fluid into the germinal layer. This process in Amphibia and Birds has been with certainty observed.***How the fluid operates, and whether and in what manner it corresponds to the male semen, is a subject for future inquiry, seeing that the effects of the latter (the semen) are still entirely unknown†".

412. The discovery of this vesicle was extended to the ova of Mollusca, Annelida, Crustacea, and Insects, as well as of some oviparous Vertebrata, by VON BAER§. This naturalist supposes "that the vesicle of PURKINJE is the important part of the ovum, performing in the female the function corresponding to that performed by the semen of the male||." He conjectures "that in proportion as the ovum approaches maturity, the vesicle is driven forward and finally destroyed between the vitellus and its membrane, before fecundation¶." He states that the germinal vesicle "disappears towards the epoch of the maturity of the ovum, entirely leaves the vitellus (as I have," says he, "particularly observed in Frogs) and no doubt then bursts, since no traces of it are subsequently found††." He remarks, "Mature ova contained in the ovaries of insects have no [germinal] vesicle, while it is found in ova which are not mature‡‡." "Is the vesicle dissolved or destroyed by the effect of fecundation? I do not believe that this can be the case, for in Frogs the ova which have descended into the oviduct are deprived of the vesicle long before fecundation§§." Respecting the ova of certain Fishes the same observer remarks, "I have hitherto found the germinal vesicle in all ova which were still in their capsules, but never in such as were discharged|||." "The germinal vesicle of Serpents and Lizards does not develop the embryo; it disappears entirely as the germinal vesicle of Birds¶¶."

413. RATHKE. "The last and most important changes, finally, which take place within the ovary, are the disappearance of the Purkinjean [or germinal] vesicle and

† Symbolæ ad ovi avium historiam ante incubationem, 1825.

‡ Article "Ei" in the "Encyclopädisches Wörterbuch," Band X. p. 112, 1834.

§ Subsequently, PURKINJE discovered it in the ova of Entozoa and Arachnida.

|| Lettre sur la Formation de l'Œuf, p. 31.

¶ Ibid. p. 30. †† Lettre, &c., Commentaire, p. 44.

‡‡ Lettre sur la Formation de l'Œuf, pp. 29, 30.

§§ Ibid. p. 30.

||| Untersuchungen über die Entwicklungsgeschichte der Fische, S. 44.

¶¶ Lettre, &c., Commentaire, p. 48.

the production of the germ. With regard to the former, I remain in a state of entire uncertainty, and can only say that I observed that vesicle in mature ova [of the Crafish] as late as in November, but have found no trace of it in the following March. The disappearance of the vesicle therefore takes place some time before the ovum leaves the ovary. With regard to the germ, it appears first to originate when the germinal vesicle disappears, and perhaps—as VON BAER with reference to animals in general has conjectured—since that vesicle bursts, its walls are dissolved, and its contents supply the foundation of the germ†. “Of the Purkinjean vesicle in the laid ova of *Oniscus aquaticus*, I have not been able to detect the least trace‡.” “I remain in entire doubt whether the ovum [of *Oniscus asellus*] brings with it into the brooding cavity a germ. But when the ovum has reached that cavity a Purkinjean vesicle is no longer to be found§.”

414. CARUS states that the germinal vesicle “on the separation of the ovum from the ovary***becomes destroyed, and forms the fluid (*Colliquamentum Malpighii*) under the germinal membrane, which then yields the essential substance for the formation of the embryo||.”

415. BURDACH. “But the ovum itself undergoes in its essential parts a change, through which the immediate foundation of the new being, namely, the germinal membrane, is formed: that is, the germinal vesicle, which has passed nearer and nearer to the circumference of the ovum and applied itself to the germinal layer, finally disappears, no doubt bursting and pouring its fluid into the germinal layer, whereupon the germinal membrane forms. Thus PURKINJE found in the ovum of the Bird, when the infundibulum of the oviduct had received it, that the germinal vesicle had disappeared, and the germinal elevation (Keimhügel) with its opening become, for the most part, effaced; but that in the passage of the ovum through the oviduct, the germinal elevation became fully dissolved, its accumulated granules gave way, and in their stead there appeared the uniform, dense, semi-transparent germinal membrane. Further observations have shown that in all other animals also, the germinal vesicle vanishes before the appearance of the germinal membrane; and we may, therefore, with PURKINJE and VON BAER, regard it as the bearer of the female generative power. But by what means its bursting is determined is still unexplained¶.”

416. VALENTIN demonstrated the existence—first announced by COSTE—of a vesicle in the mammiferous ovum, corresponding to that of PURKINJE in the Bird. “The germinal vesicle [in the ovum of the Bird]” says VALENTIN, “becomes invisible. It probably bursts, and pours its fluid first of all into the disc. It is not, therefore,

† Ueber die Bildung und Entwicklung des Flusskrebeses, p. 2, 1829.

‡ Abhandlungen zur Bildungs- und Entwicklungsgeschichte des Menschen und der Thiere. Erster Theil, p. 4, 1832.

§ Abhandlungen, &c., Zweiter Theil, p. 72, 1833.

¶ Erläuterungstafeln zur vergleichenden Anatomie. Heft III., p. 21, 1831.

¶ Die Physiologie als Erfahrungswissenschaft, Erster Band, S. 550. 551, 1835.

without reason that it has been regarded as analogous to the semen,—as a sort of female semen†.” The same author on another occasion remarks, “That in the germinal spot alone lies the sole foundation of the future germinal membrane, is scarcely probable. It is rather probable that in the transition, the collective contents of the germinal membrane undergo an inward metamorphosis, comprehending, and in the same manner changing both parts [germinal vesicle and spot]. This indeed is shown by the fact, observed by Professor WAGNER himself, that at the period of maturity [of the ovum] the granules [of the spot] become separate from one another, and new granulations arise between them. Besides, the granules of the germinal membrane are very different from the granulated substance of the delicate germinal spot, in which all isolated corpuscles certainly for the most part fail. If the very fine and delicate peculiar granular layer on the inner surface of the vitelline membrane, pass into the future germinal membrane (which however is much to be doubted, and has more against than for it), the contents of the germinal vesicle after the act of conception, could only give the substance for the central portion of the germinal membrane, out of which indeed the new individual forms, and which therefore has the greatest dignity‡.”

417. The germinal spot on the inner surface of the membrane of the germinal vesicle was discovered by RUDOLPH WAGNER, who on making known in 1834, the existence of this object, pronounced it to be “the germ.” In a subsequent paper he remarks, “Germinal spot and germinal vesicle disappear indeed as soon as the ova have left the ovary and enter the oviduct. This seems to be a constant law in the animal kingdom, and I have never observed an exception, but both elements cannot in themselves be lost. They appear only to enter into the mass of the germinal disc and to form its central part§.” “In mature ova, impregnated or susceptible of impregnation, the germinal vesicle disappears. How this takes place, whether in consequence of a sudden bursting, or through rapid dissolution and liquefaction, flattening down, diminution of its contents, &c., does not admit of being positively determined.***Thus much is certain, that the germinal vesicle has always disappeared as soon as the ovum has left the ovary.***The contents of the germinal vesicle,—in which with increasing maturity more consistent granulations frequently arise (when the germinal spot often dissolves away),—are obviously poured into the space occupied by the germinal layer, or disc, and from the anatomical situation must be first deposited in its central part.***Such increased granulations, with the disappearance of the original germinal spot, present themselves distinctly, for instance, in the scaled Amphibia; and in Birds and Mammals appear to be present as pale clear globules.*** On the immediate changes consequent upon the disappearance of the germinal vesicle we have no more than mere hypotheses; for observation has hitherto given no

† *Entwicklungsgeschichte des Menschen mit vergleichender Rücksicht der Entwicklung der Säugethiere und Vögel*, p. 28, 1835. *Edinburgh Medical and Surgical Journal*, No. 127.

‡ MÜLLER's Archiv, 1836. Heft II. pp. 168. 169.

§ Beiträge, &c., p. 40.

explanation of them.—The newer researches of SCHWANN appear to give to observation another direction, which will perhaps be more productive. It is thus possible, that the germinal vesicle is the parent cell for new cells of the germinal membrane. The new granulations into which, for instance in Amphibia and Fishes, I saw the germinal spot to become divided, are perhaps young cells in the parent cell†. The facts recorded in the present memoir show this conjecture, so far as it went, to have been very near the truth‡.

418. RICHARD OWEN, with reference to the germinal vesicle of Birds, justly remarks, "it is the essential element of the cicatricula, and the centre from which all subsequent development radiates§."

419. ALLEN THOMSON. "The vesicle of PURKINJE***has***received the name of germinal vesicle, a most appropriate term, since it may be regarded as the more immediate seat of the germ or germinating faculty of the egg||." "We do not know with certainty what befalls the vesicle of PURKINJE in the ovulum of Mammalia at the time of its escape from the ovarium. The analogy of all oviparous animals is strongly in favour of the supposition that it bursts in the same manner.***While therefore, we feel disposed to adopt the opinion that the seminal fluid, in fecundating the egg, operates its peculiar change chiefly on the germinal part, and that the bursting of the germinal vesicle is very probably connected with the change of fecundation, it must be admitted that further observations are still wanting to afford a satisfactory proof of the correctness of these hypotheses¶."

420. COSTE, with reference to the germinal vesicle in the ova of Mammalia in general, remarks, "Après la chute de l'œuf dans les trompes, on ne voit plus de traces de cette vésicule; nous chercherons à démontrer qu'à la manière de celle des oiseaux, elle se dissout pour la même finalité††." With regard to the ovum of the Sheep, the same author observes, "Lorsqu'il tombe de l'ovaire pour pénétrer dans les trompes utérines, la petite vésicule transparente (analogue de la vésicule de PURKINJE) se dissout, et ici encore se trouve confirmé ce que nous avons dit d'une manière générale de l'œuf des mammifères‡‡."

420½. JACQUEMIN. "La cicatrice et la vésicule de PURKINJE sont très développées dans l'œuf [*Planorbis cornua*] retiré de l'ovaire; ils disparaissent peu à peu pendant leur passage et leur séjour dans la matrice§§." "Le vitellus commence à se transformer en embryon immédiatement après la ponte§§."—"Le vitellus, parfaitement

† Lehrbuch der Physiologie. Erste Abtheilung, pp. 57, 58, 1839.

‡ It is due to Professor R. WAGNER to mention, that he had said it seemed to him probable, on many grounds, that the germinal vesicle is not a nucleus, as supposed by SCHWANN (par. 349.); and had stated that the germinal spot often appeared to him to contain minute nucleoli, as figured, for instance, in his *Prodromus Historiæ Generationis*, Tab. II. fig. xxx b. He had also proposed to denominate the germinal spot the "*nucleus generativus*" (Lehrbuch, &c. p. 34.).

§ Dr. TODD's Cyclopædia of Anatomy and Physiology, Article "Aves," p. 356.

|| Ibid. Article "GENERATION," p. 452. ¶ Ibid. p. 462. †† Embryogénie Comparée, p. 83, 1837.

‡‡ Ibid. p. 421.

§§ L. c., p. 674.

globuleux au moment de la ponte, présente bientôt après des taches arrondies et claires, qui ne surpassent guères 4; elles résultent de la disposition particulière des granules qui remplissent son intérieur, et qui se retirent de la circonférence vers le centre†."

421. T. WHARTON JONES. "It is known that in birds and reptiles the germinal vesicle disappears before impregnation. In the ova of the Frog, contained in the oviduct, and also in the more advanced of those contained in the ovary, no trace of the germinal vesicle is to be observed.***In the furthest advanced ova contained in the ovary of the Newt, the blastoderma was formed, and I think I perceived the place where the germinal vesicle had been. As to the ova of the Mammifera, I have found many in which there was no germinal vesicle, and which certainly had not been impregnated. It is to be remarked that in such ova the vitelline grains were for the most part coherent and formed the vesicular blastoderma. It being determined that the disappearance of the germinal vesicle is prior to impregnation and not dependent on it, the next question which arises is 'how does the germinal vesicle disappear?' My observations on the ova of the water Newt are the only ones I have which bear upon this question. From what I have observed in them I think the mode of disappearance is the following: The vesicle at first imbedded in the substance of the yolk, approaches more and more the surface of it, until it comes to lie immediately underneath the vitellary membrane, in the manner represented in fig. 12. The coat of the vesicle having become very soft and weak gives way, and the contained fluid is effused on the surrounding surface of the yolk. The coat of the vesicle being of extreme tenuity cannot be seen after it has given way. The small depression in which the vesicle was situate now forms the cicatricula, fig. 13. I think that the fluid contained in the germinal vesicle being effused gives a degree of consistence to the matter composing the surface of the yolk, and thus promotes the formation of the blastoderma‡."

422. SCHWANN. "It is of great importance to decide the question, what is the import of the germinal vesicle. Is it a young cell arising within the yolk-cell, or is it the nucleus of the yolk-cell? If the first, it is very probably the most essential foundation of the embryo; but if it be the nucleus of the yolk-cell, its importance ceases with the formation of the yolk-cell, and according to the analogy of most cell-nuclei it must subsequently be either entirely absorbed, or continue for a time, without forming any new essential object§."—"It is worth while to a certain extent, from the import of the germinal vesicle [in the physiology of cells] to determine *a priori* its subsequent destiny, and thereby to be able to give at least a clue to the much more difficult observations on the impregnated ovum||." SCHWANN subse-

† L. c., p. 660.

‡ On the first Changes in the Ova of the Mammifera in consequence of Impregnation, and on the Mode of Origin of the Chorion. Philosophical Transactions, 1837. Part II. pp. 343. 344.

§ L. c., pp. 49, 50.

|| L. c., p. 51.

quently expresses the opinion that the germinal vesicle is "the nucleus of the ovum-cell†."

423. BISCHOFF. "All the ova [of the Dog] which I found in the oviduct, still resembled in a remarkable manner the ovarian ova, viz. they always had a granular disc, just as those in the ovary, and the yolk is always still dark and untransparent. Those of the earliest age presented also scarcely any change in size or in the appearance of the yolk. With all imaginable care and pains I sought in all for the germinal vesicle, but in vain. The disappearance of this structure therefore in mammals also (where hitherto it has been admitted only hypothetically), I believe myself enabled to pronounce as a decided fact. In an impregnated bitch, which I examined 19 hours after the first coitus, and where I found the ova still in the ovary, the germinal vesicle was present. It thus probably disappears just on the exit of the ovum from the ovary. What becomes of it, I cannot tell. I decidedly believe that it bursts, and that its contents, mixed with the semen, form the spot, from which the development of the embryo proceeds‡."

Existing views regarding "Cells."

424. The nucleus of the vegetable cell received but little notice until its importance was conceived by our celebrated fellow-countryman ROBERT BROWN, who was the first to denominate this structure the *nucleus of the cell*. "This areola," says Dr. BROWN, "which is more or less distinctly granular, is slightly convex, and although it seems to be on the surface is in reality covered by the outer lamina of the cell§." "It is often nearly spherical, more or less firmly adhering to one of the walls, and projecting into the cavity of the cell¶."

425. SCHLEIDEN, struck with the constant presence of the nucleus in the cells of the very young "embryo" and of the newly-formed albumen, conceived it to be intimately connected with the origin of the cell. "In consequence of which," says the same observer, "I directed my attention to this point, and was so fortunate as to see my labours crowned with success||." "This structure," says SCHLEIDEN, "varies in its outline between the oval and the circular, as well as in its form it appears to do from the lenticular to the perfect sphere¶." After giving the dimensions of this object in various instances, he proceeds, "yet upon the whole these measurements are of little importance as they [the nuclei] grow and decrease [in size], and it cannot be determined at what period of life it is that the cytoblast [nucleus] is found††."—"In very large well-developed cytoblasts,***there is observed (whether in the interior or sunk into the surface is not yet clear to me) a minute sharply circumscribed body which, judging by the shadow, appears to present a *thick ring* or a thick-walled hollow glo-

† L. c., p. 259.

‡ R. WAGNER's Lehrbuch, &c., p. 95, 1839.

§ Transactions of the Linnean Society, vol. xvi. p. 710, &c., to which I refer for further information communicated by the same author, on the Nucleus of the cell.

|| Beiträge, &c., MÜLLER's Archiv, 1838, Heft II. p. 139.

¶ Ibid. pp. 139. 140.

†† Beiträge, &c., MÜLLER's Archiv, 1838, Heft II. p. 140.

bule. In less developed cytoblasts there is observed only the outer sharp contour of this ring, and in its middle an opaque point.***In cytoblasts still smaller, it appears only as a sharply circumscribed spot; which is most frequently the case.***Or finally there is seen only a remarkable, minute, opaque point. In the very smallest and most transitory cytoblasts I have not hitherto been able to detect it†.—“From my observations in all plants which admitted of a complete tracing of the whole formative process, it follows that this minute body forms even earlier than the cytoblast.*** The size of this corpuscle also varies considerably, from the extent of half the diameter of the cytoblast to points immeasurably small.***Sometimes it appears more opaque, sometimes more pellucid than the rest of the substance of the cytoblast. For the most part it is more consistent than the latter, and remains still sharply circumscribed, when this by pressure has become changed into an amorphous mucus‡.” “As soon as the cytoblasts have attained their full size there rises upon them a fine, transparent vesicle. This is the young cell, which at first presents a very flat segment of a sphere, the plane side of which is formed by the cytoblast, and its convex side by the young cell which is situated on it, somewhat like a watch-glass on a watch.***Gradually now the entire cell grows out over the margin of the cytoblast, and speedily becomes so large, that at last the latter appears only as a minute body inclosed in one of the walls of the cell,***in which situation it accompanies through the whole vital process the cell which it has formed, if it be not (as in cells destined for higher development) either absorbed in its original situation, or—after having been cast off as a useless member—dissolved and absorbed in the cavity of the cell.—The formation of secondary deposits on the inner surface of the cell-wall does not commence, so far as I could observe, until after the absorption of the cytoblast§.” “A cell never shows a trace of a spiral formation***until full-grown, that is, until it has absorbed the cytoblast||.” “The [spiral] fibres never form free, but in the interior of cells; and the walls of these cells in an early state are simple and for the most part very delicate¶.”

426. *Ova found in the Fallopian Tube and Uterus of the Rabbit.*

The two following Tables are a continuation of those given in the “Second Series;” the object being, as then, to facilitate the discovery of the minuter ova in the Rabbit, by affording a general idea of their locality and size at different periods. They also serve to show that in both of these respects the ova of different individuals are subject to variation;—that there frequently exist considerable differences in the size and condition of ova destined to constitute the same litter of young;—and that there is no fixed relation between the degree of development of ova and their size, locality, or age.

† Beiträge, &c., MÜLLER's Archiv, 1838, Heft II. p. 141.

‡ L. c., pp. 141. 142.

§ L. c., pp. 145. 146.

|| L. c., p. 150.

¶ L. c., p. 153.

427. *Ova found in the Fallopian Tube of the Rabbit.*

Hours post coitum.	Number of ova found.	Diameter in fractions of a Paris line.	Condition of the essential portion of the ovum.	Locality.
Hours. 10 to 68½	93	⅓ to ½	{ Described in Table of "Second Series," par. 319.	{ Described in Table of "Second Series," par. 319.
10		?	Plate XXIV. fig. 191, &c.	{ Ovarian side of the middle of the tube.
11	8	⅓ to ⅔	Plate XXV. figs. 194. 195. 199.	{ Occupying the second fourth of the tube.
12	8	about ⅓	{ "Second Series," Plate XXVII. fig. 103.	{ Ovarian side of the middle of the tube.
13	6	about ⅓ +	{ Plate XXIV. fig. 193. Plate XXV. fig. 200, &c.	{ Middle of the tube.
13	10	⅓ to ⅔	Some of the upper figs. in Plate XXV.	{ Middle of the tube.
14	5	about ⅓ +	Plate XXIV. fig. 185, &c.	{ Middle of the tube.
17	6	⅓ to ⅔	Plate XXIV. figs. 188 to 192.	{ Near the middle of the tube.
21½	5	⅓ to ⅔	Plate XXIV. fig. 191, &c.	{ Uterine side of the middle of the tube.
23½	11	⅓ - to ⅔	Plate XXVI. figs. 206. 208. 209, &c.	{ Middle of the tube.
24½	8	about ⅓	{ Plate XXIV. figs. 186. 187. Plate XXV. fig. 204. Plate XXVI. fig. 207, &c.	{ Between the middle of the tube and the uterus.
35	7	⅓ - to ⅔	{ Plate XXVI. fig. 210. Plate XXIV. fig. 188, &c.	{ Between the middle of the tube and the uterus.
36	8	⅓ to ½	{ Plate XXVI. figs. 211 to 213 B. Plate XXIV. figs. 188, &c.	{ Middle third of the tube.
52	8	about ½ -	{ Plate XXVI. The lowest line of figures.	{ Chiefly occupying the uterine fourth of the tube.
57½	7	⅓ to ½	Plate XXVI. figs. 214 to 219, &c.	{ Throughout the tube, except the ovarian fourth.
57½	5	½ - to ⅔ +	{ Plate XXVII. figs. 223 to 228. 232. 233, &c.	{ Uterine third of the tube.
62	13	½ to ⅔ +	{ Plate XXV. fig. 197. Plate XXVI. fig. 220, &c.	{ Uterine fourth of the tube.
62	6	½ to ⅔	Plate XXVII. figs. 230. 231, &c.	{ Uterine extremity of the tube.
64½	6	½ to ⅔	Plate XXVII. fig. 229, &c.	{ Uterine extremity of the tube.
66	4	½ - to ⅔	{ Plate XXVII. Middle row of figures, &c.	{ Uterine extremity of the tube. Three others were found in the uterus. See next Table.
72	2	½ and ⅔ +	Plate XXVII. fig. 232, &c.	{ Uterine extremity of the tube. Three others were found in the uterus. See next Table.
	230			

Some of the Ova found in the Uterus of the Rabbit.

Hours post coitum.	Number of ova found.	Diameter in fractions of a Paris line.	Condition of the essential portion of the ovum.	Locality.
Hours. 79½ to 131½	163	⅓ to 1½	{ Described in Table of "Second Series," par. 319.	{ Described in Table of "Second Series," par. 319.
52		½ to ⅔ -	Plate XXV. figs. 202. 203. 205, &c.	{ Various.
66	3	about ⅔ +	{ Plate XXV. fig. 196. Plate XXVII. middle row of figures, &c.	{ Near the Fallopian tube. Four others were found in the Fallopian tube. See Table above.
72	3	⅔ + to ⅔ +	Plate XXVII. fig. 232, &c.	{ Near the Fallopian tube. Two others were found in the Fallopian tube. See Table above.
76½	7	⅔ + to ⅔ +	Plate XXVII. fig. 234, &c.	{ All within 1½ inch of the Fallopian tube.
	181			

It will be seen from these Tables, that ova have been found in the Fallopian tube as late as 72 hours; and in the uterus as early as 52 hours, *post coitum*.

428. Table, showing (from ova of ten Rabbits) that the diameter of the chorion is liable to much greater variation than that of the thick transparent membrane *f.* (par. 365.) An asterisk (*) denotes that the ovum was taken from the uterus, the other ova having been found in the Fallopian tube. The measurements are expressed in fractions of a Paris line.

Hours post coitum.	Diameter of	
	Chorion. Cho.	<i>f.</i> Thick transparent membrane.
Hours. 57½	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{10} +$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8} +$	$\frac{1}{11}$
	$\frac{1}{8} -$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{10}$
	$\frac{1}{8}$	$\frac{1}{11}$
62	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8} -$	$\frac{1}{11} -$
	$\frac{1}{8} -$	$\frac{1}{11} +$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8} -$	$\frac{1}{10}$
62	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} -$	$\frac{1}{11} +$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
Hours post coitum.	Diameter of	
	Chorion. Cho.	<i>f.</i> Thick transparent membrane.
Hours. 64½	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11} +$
66	$\frac{1}{8} -$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11} +$
	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11} -$
72	$\frac{1}{8}$	$\frac{1}{11} +$
	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11}$
	$\frac{1}{8} +$	$\frac{1}{11}$
	$\frac{1}{8} +$	$\frac{1}{11} +$
	$\frac{1}{8} +$	$\frac{1}{11} +$
76½	$\frac{1}{8} -$	$\frac{1}{10} +$
	$\frac{1}{8} -$	$\frac{1}{10}$
	$\frac{1}{8} -$	$\frac{1}{10}$
	$\frac{1}{8}$	$\frac{1}{11} +$
	$\frac{1}{8} +$	$\frac{1}{10} +$
	$\frac{1}{8} +$	$\frac{1}{10} +$
	$\frac{1}{8} +$	$\frac{1}{10} +$
Hours post coitum.	Diameter of	
	Chorion. Cho.	<i>f.</i> Thick transparent membrane.
Hours. 57½	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8} -$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11} -$
	$\frac{1}{8} -$	$\frac{1}{11} -$
36	$\frac{1}{8} -$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{10}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11} -$
24½	$\frac{1}{8}$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11} +$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8} +$	$\frac{1}{11}$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$
	$\frac{1}{8}$	$\frac{1}{11} -$

429. Table of Measurements.

The measurements are given in fractions of a Paris line (^m), the micrometer used, one of FRAUENHOFER's, being divided according to French measure. The French inch (of twelve lines) is to the English inch, as 1·06575 is to 1·00000, or nearly one fifteenth more. Assuming it to be exactly one fifteenth more, the simplest mode of converting the fraction of a French line into the fraction of an English inch, will be to multiply the denominator of the former by the number 11·25 (or 11½). Thus the actual length of the cell in Plate XXVII. fig. 225, which measured $\frac{1}{10}$ of a Paris line, is found to have been about $\frac{1}{1125}$ of an English inch. (The nucleus of this cell is the rudimental embryo.)

When the object is not spherical, it is the long diameter, the measurement of which is given in the Table.

The diameter of many objects contained within larger ones has been omitted, because it may be inferred; the scale being the same.

Table of Measurements.

No. of Figure.	Diameters magnified.	Actual diameters in fractions of a Paris line.				
		Cho. Cho- rion.	Thick trans- parent mem- brane— "zona p."	Germinal vesicle.	Germ.	Cells of the Germ.
156	100	.....	$\frac{1}{18}$ —			
157	100	.....	$\frac{1}{18}$			
158	50	.....	$\frac{1}{18}$ +			
159	100	.....		$\frac{1}{30}$ —		
160	100	.....	$\frac{1}{18}$	$\frac{1}{30}$		
162	100	.....	$\frac{1}{11}$	$\frac{1}{30}$ +		
164	100	.....	$\frac{1}{18}$			
165	100	.....	$\frac{1}{18}$			
167	100	.....	$\frac{1}{18}$			
169	100	.....	$\frac{1}{18}$ —			
170	50	.....	$\frac{1}{18}$			
171	50	.....	$\frac{1}{18}$			
172	100	.....	$\frac{1}{18}$			
173	50	.....	$\frac{1}{18}$			
174	100	.....	$\frac{1}{18}$			
175	100	.....	$\frac{1}{18}$			
176	100	.....	$\frac{1}{18}$ +			
178	100	.....	$\frac{1}{18}$			
179	50	.....	about $\frac{1}{11}$			
180	50	.....	$\frac{1}{18}$			
181	100	.....	$\frac{1}{18}$			
185	100	.....	$\frac{1}{18}$ +			
186	100	about $\frac{1}{11}$				
187	100	about $\frac{1}{11}$		about $\frac{1}{18}$		
188	100	.....	$\frac{1}{18}$			
189	300	.....	$\frac{1}{18}$			
190	100	$\frac{1}{18}$				
191	100	.....	$\frac{1}{18}$		$\frac{1}{30}$	
192	300	.....	$\frac{1}{18}$			$\frac{1}{18}$
193	100	.....	$\frac{1}{18}$ +	about $\frac{1}{18}$	$\frac{1}{30}$	
194	100	.....	$\frac{1}{18}$			
195	100	.....	$\frac{1}{18}$	$\frac{1}{30}$		
196	100	$\frac{1}{8}$ +				
197	100	$\frac{1}{8}$				
198	100	.....	$\frac{1}{18}$	$\frac{1}{30}$		about $\frac{1}{30}$
199	100	.....	$\frac{1}{11}$			
200	100	.....	$\frac{1}{18}$ +			

Table of Measurements. (Continued.)

No. of Figure.	Diameters magnified.	Actual diameters in fractions of a Paris line.					
		Cho. Cho- rion.	f. Thick trans- parent mem- brane— "zona p."	e. Germinal vesicle.	As. Germ.	Cells of the Germ.	Miscellaneous objects.
201	100	.....	about $\frac{1}{15}$				
202	100	$\frac{1}{8}$	$\frac{1}{10}$				
203	100	$\frac{1}{8}$	$\frac{1}{10}$				
204	100	about $\frac{1}{11}$					
205	100	$\frac{1}{8} -$	$\frac{1}{15} +$				
206	50	.....	about $\frac{1}{15}$				
207	100	$\frac{1}{11}$					
208	100	.....	$\frac{1}{15}$				
209	50	.....	$\frac{1}{15}$				
210	100	about $\frac{1}{10}$	.....			about $\frac{1}{35}$	
211	100	$\frac{1}{8} -$	$\frac{1}{15}$				
212	100	$\frac{1}{8}$	$\frac{1}{11} -$				
213 A	100	$\frac{1}{8}$	$\frac{1}{15}$			about $\frac{1}{50}$	
213 B	100	$\frac{1}{8}$	$\frac{1}{15}$			about $\frac{1}{50}$	
214	100	$\frac{1}{8}$	$\frac{1}{10}$			$\frac{1}{50} -$ to $\frac{1}{50}$	
215	100	$\frac{1}{8}$	$\frac{1}{10}$				
216	100	$\frac{1}{8}$	$\frac{1}{10}$			$\frac{1}{50}$ to $\frac{1}{50}$	
219	100	$\frac{1}{8}$	$\frac{1}{8}$				
220	100	$\frac{1}{8} -$	$\frac{1}{11}$		$\frac{1}{15}$		
223	100	$\frac{1}{8}$	$\frac{1}{11}$		$\frac{1}{50}$	about $\frac{1}{75}$	
224	100	$\frac{1}{8} -$	$\frac{1}{11}$		$\frac{1}{50} +$		
225	100	.....	.....				$\frac{1}{50}$
228	300	$\frac{1}{8}$	$\frac{1}{11} -$				
229	100	$\frac{1}{8}$	$\frac{1}{15}$				
230	100	$\frac{1}{8}$	$\frac{1}{15}$				
231	100	$\frac{1}{8}$	$\frac{1}{11}$				
232	100	$\frac{1}{8}$	$\frac{1}{11} +$				
233	100	$\frac{1}{8} +$	$\frac{1}{11} -$		$\frac{1}{50}$		
234	100	$\frac{1}{8}$	$\frac{1}{15} +$				
244	50	.....	.....				$\frac{1}{8}$
245	300	.....	.....				$\frac{1}{50}$ and less.
248	.....	.....	.....				$\frac{1}{50}$ and larger.
249	.....	.....	.....				$\frac{1}{50}$ and larger.
250	300	.....	.....				about $\frac{1}{500}$
251 a	.....	.....	.....				$\frac{1}{500}$
251 β	.....	.....	.....				$\frac{1}{100}$
251 γ	.....	.....	.....				$\frac{1}{50}$
252	.....	.....	$\frac{1}{11} -$				
253	.....	.....	$\frac{1}{11} +$				

430. EXPLANATION OF THE PLATES.

N.B. In all the figures the same letters denote the same objects; as may be seen by the explanation at the foot of each Plate. The same letters are used as in the First and Second Series. (These remarks, however, do not apply to the letters α , β , γ , in Plate XXVIII.) The term "*Rudimental Embryo*" is applied to the object *bb*, instead of "*Germ*," employed in the Second Series; and "*Germ*" is now applied to the object *bs*.

- b.* Germinal spot beginning to resolve itself into cells.
- bs.* Twin cells—foundation of the new being—germ—group of cells—mulberry-like object.
- bb.* Rudimental embryo.—("Germ" of Second Series.)
- c.* Germinal vesicle, more or less filled with cells.
- e.* Proper membrane of the substance by which the germinal vesicle is surrounded.
- f.* Thick transparent membrane of the ovum—"zona pellucida."
- f*¹. Fluid imbibed by the chorion.
- g*¹. Cells of the tunica granulosa.
- g*². Cells of the retinacula ovi.
- cho.* Incipient chorion—chorion (becoming villous in the uterus).

PLATE XXII.

(All the Figures are from the Rabbit (*Lepus Cuniculus*, LINN.)).

Fig. 156. An ovarian ovum of $\frac{1}{4}$ "^m. The Graafian vesicle—about $\frac{1}{3}$ "^m—from which it was taken, exhibited no appearance of preparation for discharging its ovum, while a number of others in the same ovary had obviously been destined to do so. (The animal was killed seven hours *post coitum*.) This figure represents the substance lying immediately within the thick transparent membrane *f*, namely a layer of regularly elliptical and flattened objects—discs—each of which contained minuter objects of the same kind, concentrically arranged around a pellucid point (par. 337.). The germinal vesicle (*c*) was spherical. The germinal spot (*b*), directed towards the surface of the ovum, exhibited incipient cells at its free part (par. 327.). The centre of the spot was pellucid. 100 *diameters*.

Fig. 157. An ovarian ovum of $\frac{1}{8}$ "^m. The Graafian vesicle containing it (about $\frac{1}{4}$ "^m) presented no appearance of preparation for discharging its ovum, while several others in the same ovary were in a state of forwardness in this respect. (The animal was killed $5\frac{1}{4}$ hours *post coitum*.) The objects on the inner surface of the membrane *f* differed from those of the preceding figure, in many of them appearing to have undergone partial

liquefaction (par. 337.). There was a cavity in the centre of the ovum, into which the germinal vesicle (c) projected. This vesicle, still globular, seemed filled with cells, into which the free portion of the germinal spot had been resolved (see the explanation of the preceding figure). 100 diam. (pars. 327.)

- Fig. 158. An ovarian ovum of seven hours, and measuring in diameter $\frac{1}{15}''$ +. Its Graafian vesicle was of considerable size. (The membrana granulosa escaped nearly entire along with this ovum.) 50 diam.
- Fig. 159. The germinal vesicle ($\frac{1}{30}''$ —) of the ovum in the preceding figure. As seen in profile, its form resembled that of the crystalline lens of the eye. 100 diam. (pars. 327. 330 and 331.)
- Fig. 160. An ovarian ovum of $\frac{1}{18}''$, in a state nearly prepared for fecundation. It was taken from a Rabbit in the state of heat. The germinal vesicle (c) had become flattened, but its size (about $\frac{1}{30}''$) was less than that of the germinal vesicle in the ovum fig. 162. The free portion of the germinal spot had resolved itself into cells, and the foundations of other cells had come into view, arranged in concentric layers. (The altered spot thus fills the vesicle, and seems to keep pace with it in its enlargement by the origin of new cells in the centre (par. 327.). This centre of the altered germinal spot is the future point of fecundation. It continues at the periphery of the germinal vesicle until the ovum has been fecundated, being until then directed towards the surface of the ovum, and towards the surface of the ovary.) In this ovum, the discs immediately internal to the membrane *f* were indistinct from partial liquefaction. The ovum presented a cavity in its centre containing fluid, in which were a few pale globules (par. 337.). A sort of canal proceeded from this cavity to the germinal vesicle. (The cells of the tunica granulosa had become loosened. They are not represented in the figure.) 100 diam.
- Fig. 161. The pellucid centre of the altered germinal spot in the ovum fig. 160. Around this point are two concentric layers of incipient cells (pars. 327. 328.). 300 diam.
- Fig. 162. An ovarian ovum of $\frac{1}{11}''$. The Graafian vesicle containing it was large and vascular, and found in the same ovary as that which yielded the objects in the two preceding figures. The animal was in the state of heat. This ovum seemed still more completely prepared for fecundation than that in fig. 160, from which it differed in the following respects; namely, the germinal vesicle (c) was larger ($\frac{1}{30}''$ + in its transverse diameter), and the concentric layers of more or less incipient cells in its interior had increased in number, from the origin of new ones internal to the rest (par. 327.). Liquefaction of the objects immediately under

the membrane *f* was more complete, and a globular mass, having a cavity in its interior, occupied the centre of the ovum (par. 337.). This mass consisted of elliptical compound discs, resembling those described in the explanation of fig. 156 (par. 337.). (The cells of the tunica granulosa of the ovum in the present figure had become loosened. In two other ova in a similar condition, from the same ovary, the membrane *f* presented an orifice at the part immediately above the point of fecundation.) 100 *diam.*

Fig. 163. The pellucid centre of the altered germinal spot in an ovum from the same ovary which yielded the objects figs. 160. 161 and 162. (The germinal vesicle—about $\frac{1}{30}''$ —filled with incipient cells in concentric layers, resembled in position, form, and size, that (*c*) in fig. 162; but the ovum itself was smaller— $\frac{1}{13}''$.) The space inclosed by the dotted line in the present figure, was pellucid and measured in diameter $\frac{1}{30}''$. 300 *diam.* (par. 327.).

Fig. 164. An ovarian ovum of seven hours, and measuring in diameter $\frac{1}{4}''$. Its Graafian vesicle was very large. The contents of the germinal vesicle (*c*) were less pellucid than those of the germinal vesicle represented in fig. 162, another layer of incipient cells having come into view (par. 326.). The objects (now cells) under the membrane *f*, very regularly elliptical and flattened, were circumscribed by a proper membrane (pars. 338. 339. 342. 343. 360.), which at a certain part presented a depression (orifice?). This part lay immediately under an opening in the membrane *f* (pars. 332 to 335.). 100 *diam.*

Fig. 165. An ovarian ovum of four hours, and measuring in diameter $\frac{1}{3}''$, taken from a Graafian vesicle which was large but not particularly vascular. This ovum, though smaller than that in fig. 162, resembled it in general appearance. The membrane *f* exhibited an orifice (pars. 332 to 335.) at the part immediately under which was situated the pellucid centre of the altered germinal spot—the situation of the future point of fecundation. A little external to this centre there was also a pellucid space. The part surrounding the latter was obscure. 100 *diam.*

Fig. 166. The pellucid centre of the altered germinal spot in the ovum of the preceding figure, as seen lying immediately under the orifice in the membrane *f*: with a surrounding layer of incipient cells. About 300 *diam.* (par. 328.).

Fig. 167. An ovarian ovum of $5\frac{1}{4}$ hours, and measuring in diameter $\frac{1}{3}''$. Its Graafian vesicle was vascular, but not very large. The objects corresponding to those which in the ova figs. 162 and 165. lay immediately under the membrane *f*, had undergone entire liquefaction—leaving a pellucid fluid in their place; and the globular mass—correspond-

ing to that which in the ova figs. 162 and 165. consisted of regularly elliptical compound discs—exhibited in the present ovum an irregular structure, the cells, into which its discs had passed, appearing to have become pressed into irregular shapes, or partially broken down; and the mass they constituted was distinctly circumscribed by a membrane, *e* (pars. 338. 339. 342. 343. 360.). Of the germinal vesicle (*c*) nothing could be distinctly seen besides its outline, and the pellucid centre of the altered germinal spot. This centre lay immediately under an orifice in the membrane *f* (pars. 332 to 335.). In this orifice an object was observed resembling a Spermatozoon in the act of entering the ovum (par. 334.). (Part of this object is represented in the next figure.) The orifice was very obvious in this ovum, and seen with more or less distinctness in five other ova of the same Rabbit. 100 *diam*.

- Fig. 168. The large extremity of the object resembling a Spermatozoon, observed in the orifice of the membrane *f* in the preceding figure. It presented in its interior a pellucid point, similar to that seen in certain states of the germinal spot, and in the elliptical discs which occur in so many figures accompanying the present paper (par. 334.). About 300 *diam*.

PLATE XXIII.

All the Figures are from the Rabbit (Lepus Cuniculus, LINN.).

- Fig. 169. A fecundated ovarian ovum of $5\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{18}^m$. (Its Graafian vesicle was large and vascular.) The germinal vesicle (*c*)—filled with cells (pars. 329. 382.)—appeared to be returning to the centre of the ovum. It is probable that the ovum had only just been fecundated, for the point of fecundation was still at the surface of the germinal vesicle. (It subsequently passes to the centre.) (par. 341.) The substance contained within the membrane *f* seemed to be surrounded by a proper membrane, *e* (pars. 338. 339. 342. 343. 360.). The membrane *f* was distinctly cleft above the point of fecundation (pars. 332 to 335.). (The cells of the tunica granulosa had become club-shaped, and radiated from the ovum in the manner shown at *g*¹ in figs. 173. 181 and 195 (par. 345.). The tunica granulosa also exhibited a depression similar to that represented in fig. 173, this being apparently the effect of pressure towards the exterior of the ovary.) 100 *diam*.
- Fig. 170. A fecundated ovarian ovum of $8\frac{1}{4}$ hours, and measuring in diameter $\frac{1}{4}^m$. This figure presents a *superficial* view of the ovum. The germinal vesicle had left the surface of the ovum, but its situation was not quite central. It had become closely surrounded by cells, each of which pre-

sented a remarkable, opaque nucleus (par. 342.). The space around these cells was occupied by larger cells, apparently undergoing liquefaction. 50 diam.

Fig. 171. A fecundated ovarian ovum of $8\frac{1}{4}$ hours, and measuring in diameter $\frac{1}{4}'''$, from the same ovary as that in the preceding figure. It was apparently in a similar condition. It is not (as in fig. 170.) the surface, but the interior of the ovum that is here seen. The point of fecundation had now reached the centre of the germinal vesicle (c). (See the explanation of fig. 169.) 50 diam. (par. 341.)

Fig. 172. A fecundated ovarian ovum of $8\frac{1}{4}$ hours, and measuring in diameter only $\frac{1}{8}'''$ (par. 365.). The cells under the membrane *f* were circumscribed by a proper membrane (*e*), between which and the membrane *f* there was a space filled with transparent fluid (pars. 338. 339. 342. 343. 360.). The centre of the ovum was occupied by the germinal vesicle, around which were large, regularly elliptical, and flattened cells. These cells possibly corresponded to those occupying a similar situation in figs. 170 and 171: but they were in a more advanced state. 100 diam.

Fig. 173. A fecundated ovarian ovum of six hours, and measuring in diameter $\frac{1}{8}'''$. (Its Graafian vesicle was large.) This ovum differed from that of the preceding figure in having a layer of minute cells around the germinal vesicle (c), not observed in the ovum of the preceding figure. The mass of large cells external to these was surrounded by a proper membrane (*e*) (pars. 338. 339. 342. 343. 360.). Immediately under the membrane *f*, were the remains of cells undergoing liquefaction. The membrane *f* still presented an orifice (par. 344.), not seen in the ovum fig. 172. (In the latter it had possibly closed) (par. 344.). At *g*¹ are the cells of the tunica granulosa, which had become elongated, and club-shaped, and were in contact with the membrane *f* by their pointed extremities alone (par. 345.). The tunica granulosa exhibited around the orifice, in the membrane *f*, a depression—apparently the effect of pressure towards the exterior of the ovary (par. 335.). 50 diam.

Fig. 174. The same ovum in outline, on a larger scale; the tunica granulosa being omitted. 100 diam. (pars. 344. 360.)

Fig. 175. A superficial view of the same ovum as that in the two preceding figures. 100 diam. (pars. 344. 360.)

Fig. 176. A fecundated ovarian ovum of $8\frac{1}{4}$ hours, and measuring in diameter $\frac{1}{8}'''$ +. It differed from the ovum fig. 175. in the following respects, namely: The cells apparently corresponding to those, the remains of which in the ovum fig. 175. were seen immediately under the membrane *f*, had entirely liquefied, leaving a transparent fluid in their place; and cells possibly corresponding to the large ones which in the ovum fig.

175. entered into the formation of the central mass, appeared in their turn to be undergoing liquefaction, but were still circumscribed by a membrane (*e*) (pars. 338. 339. 342. 343. 360.); while another set of cells, perhaps corresponding to the minute ones surrounding the germinal vesicle (*c*) in the ovum figs. 173. (174. 175.), had become very large. 100 *diam.*

Fig. 177. Section showing the structure of one of the compound discs of which the substance surrounding the germinal vesicle in some states consists; a structure which appears to be essentially the same—differing only in degree—in all the compound discs met with in the evolution of the ovum. This figure is for the most part in outline. 300 *diam.* (pars. 337. 382. 383.)

Fig. 178. A fecundated ovarian ovum of nine hours, and measuring in diameter $\frac{1}{15}''$. Immediately under the membrane *f*—and without a proper investing membrane (pars. 338. 339. 342. 343. 360.)—were large cells, filled with the foundations of other cells; the latter in concentric layers surrounding a pellucid point. 100 *diam.*

Fig. 179. A fecundated ovum of nine hours, and measuring in diameter about $\frac{1}{15}''$. It was taken from the same ovary as the ovum in the preceding figure. The cells under the membrane *f*—without a proper investing membrane (pars. 338. 339. 342. 343. 360.)—were even larger than those in fig. 178, presented minuter cells between them (par. 351.), and were undergoing liquefaction. The point of fecundation was seen in the centre of this ovum. 50 *diam.*

Fig. 180. Another fecundated ovarian ovum of nine hours, and measuring in diameter $\frac{1}{15}''$, from the same Rabbit as the ova in figs. 178 and 179. The large cells under the membrane *f* were not circumscribed by a proper membrane, and seemed to be undergoing liquefaction (pars. 338. 339. 342. 343. 360.). 50 *diam.*

Fig. 181. A fecundated ovarian ovum of ten hours, and measuring in diameter $\frac{1}{15}''$. The substance under the membrane *f* seemed to be invested by a proper membrane, *e* (pars. 338. 339. 342. 343. 360.). This figure represents the cells of the tunica granulosa (*g*¹) in their altered, club-like form. Each of these cells, at this period, is in contact with the membrane *f* by its pointed extremity alone (par. 345.). 100 *diam.*

PLATE XXIV.

All the Figures are from the Rabbit (Lepus Cuniculus, LINN.), except fig. 183.

Figs. 182. 183 and 184, are copies of all the delineations of ova from the Fallopian

tube which had been published before the Second Series of these researches (par. 322.).

Fig. 182. From CRUIKSHANK.

"The figures marked third day, are ova of the Fallopian tube, found after impregnation on that day. The three first are of the natural size; the three next are magnified, in the simple microscope. In all of them the chorion and amnion are even now distinct, and in some of them the *allantois*, as I suspect†.

"The figures marked $3\frac{1}{2}$ day, are ova still more advanced; similar to which I found many in the tubes, many in the horns of the uterus. The three first are of the natural size; the two following are magnified also in the simple microscope‡."

Fig. 183. From BARR. "Œuf de chien retiré de la trompe utérine.***Grossi trente fois" (par. 322.)§.

Fig. 184. From T. WHARTON JONES. "An ovum found in the Fallopian tube of a Rabbit the third day after impregnation; magnified forty diameters||" (par. 322.). This ovum is described by JONES as having measured in diameter " $\frac{1}{10}$ th of an inch," that is about $\frac{1}{8}$ mm; and being an ovum of "the third day," it admits of comparison with the delineations of ova in Plate XXVII. figs. 229 to 234. T. WHARTON JONES conjectures "that the gelatinous coat [see Plate XXIV. fig. 184.] acquired by the ovum in the ovary [as he supposes], and more especially circumscribed and defined after impregnation, constitutes the only covering of the vesicular blastoderm after the giving way of the vitellary membrane; that this gelatinous-looking coat forms the chorion, which in the rodents at a further stage of development presents itself under the form of a thin and transparent membrane, very like the vitellary membrane of the bird's egg, situated immediately outside the non-vaseular and reflected layer of the umbilical vesicle" (l. c., p. 342.). (Contrast this with the description of the mode, the period, and the place of origin of the chorion, as given in the "Second Series" of these researches, pars. 172. 173. 178. 182. 221 to 225, and in the present memoir, pars. 372 to 374.) With reference to the interior of the ovum Plate XXIV. fig. 184, T. WHARTON JONES remarks, "The granulary matter of the yelk was coherent" (l. c., p. 339.).

Fig. 185. An ovum of fourteen hours from the middle of the Fallopian tube; the membrane *f* measuring in diameter $\frac{1}{14}$ mm+. The outer surface of this membrane was covered with cells (*cho.*), coalescing to form the rudi-

† Philosophical Transactions, 1797, p. 212.

‡ Ibid. p. 212.

§ Lettre sur la Formation de l'Œuf, p. 62. fig. III*.

|| Philosophical Transactions, 1837. Part II., p. 345.

mental chorion (par. 372.). On the left side, this process was more advanced than elsewhere (see figs. 252 and 253.). The cells internal to the membrane *f* were invested by a proper membrane, between which and the membrane *f* there was a considerable space filled with colourless and transparent fluid (pars. 338. 339. 342. 343. 360.). This fluid contained two minute cells which had escaped liquefaction (par. 350.). They presented objects in their interior. 100 diam.

Fig. 186. An ovum of $24\frac{1}{2}$ hours from the uterine side of the middle of the Fallopian tube, measuring in diameter about $\frac{1}{11}''$. The incipient chorion (*cho.*) was beginning to imbibe a transparent colourless fluid (*f*¹), and to rise from the membrane *f* (par. 374.). The cells internal to the membrane *f* were invested by a proper membrane, between which also and the membrane *f* there was a colourless transparent fluid (pars. 338. 339. 342. 343. 360.). In this fluid there was a minute cell which had escaped liquefaction (par. 350.). This minute cell contained several still minuter cells. It is a superficial view of the ovum which is presented in this figure. 100 diam.

Fig. 187. An ovum of $24\frac{1}{2}$ hours from the uterine side of the middle of the Fallopian tube, measuring in diameter about $\frac{1}{11}''$. The incipient chorion (*cho.*) was beginning to imbibe fluid (*f*¹), and to rise from the membrane *f* (par. 374.). The cells in the central portion of the ovum were invested by a proper membrane (*e*), between which and the membrane *f* there was a fluid (pars. 338. 339. 342. 343. 360.). In the latter were two minute cells which had escaped liquefaction (par. 350.), their interior presenting cells still more minute. This figure exhibits a section of the ovum through its centre. The germinal vesicle (*c*) was still visible, and measured in diameter about $\frac{1}{15}''$. It was filled with cells, two of which (*bs*)—larger than the rest, but still incipient only (par. 346.)—occupied the place in which the point of fecundation is last seen. The minute cells immediately surrounding these two larger ones, were arranged in a layer. 100 diam.

Fig. 188. An ovum of seventeen hours from the Fallopian tube near the middle part, measuring in diameter $\frac{1}{13}''$. It was taken from the same Rabbit as the ova of figs. 190 and 191. The cells in the central portion of the ovum were invested by a proper membrane, *e* ($\frac{1}{10}''$), which however had become thin preparatory to its disappearance (pars. 338. 339. 342. 343. 360.). Those cells seemed to be undergoing liquefaction. Between them were minuter cells, which, as well as the objects in the centre of the larger cells, appeared like an assemblage of black points until viewed—as in the following figure—with a higher power (par. 351.). 100 diam.

Fig. 189. Part of the same ovum more highly magnified. The minute intermediate cells are here seen to have had essentially the same structure as the larger ones. The dark objects in the latter were composed of the foundations of cells, which seemed to surround a central space. 300 diam. (par. 351.)

Fig. 190. An ovum of seventeen hours from the Fallopian tube near its middle, and measuring in diameter $\frac{1}{3}$ ". It was taken from the same Rabbit as the ova in figs. 188 and 191. The incipient chorion (*cho.*) was beginning to imbibe fluid, and to rise from the membrane *f* (par. 374.). The cells in the central portion of the ovum were invested by a proper membrane, *e* ($\frac{1}{3}$ "). Those immediately within this membrane were pretty large, and seemed to be undergoing liquefaction (pars. 338. 339. 342. 343. 360.). Internal to these were smaller cells (surrounding two large ones corresponding to the two which occupied the centre of the ovum in fig. 191). 100 diam.

Fig. 191. An ovum of seventeen hours from the Fallopian tube near its middle, and measuring in diameter $\frac{1}{4}$ ". It was taken from the same Rabbit as the ova in figs. 188 and 190. The condition of the interior of the ovum appeared to be nearly the same as that of the ovum fig. 190. The most central part was occupied by two large elliptic cells (*bs*) of equal size ($\frac{1}{50}$ " in length), surrounded by minute dark objects (par. 351.), and containing a colourless transparent fluid and a nucleus (par. 378.); the latter presenting in its centre a brilliantly pellucid space. These two large cells were in the same locality as the two in fig. 187; namely, that in which the point of fecundation is last seen. They constitute the essential portion of the ovum, that is, the germ (par. 347.). 100 diam.

Fig. 192. The nucleus of one of the twin cells represented in the preceding figure. It measured in diameter about $\frac{1}{130}$ ", and the pellucid space in its centre about $\frac{1}{30}$ ". The outer portion of this nucleus appeared to consist almost entirely of the foundations of new cells. 300 diam. (pars. 347. 380.)

Fig. 193. An ovum of thirteen hours from the middle of the Fallopian tube, measuring in diameter $\frac{1}{3}$ " +. The membrane *f* was surrounded by minute cells (*cho.*), destined to coalesce and thus give origin to the chorion (par. 372.). Only a few of these have been represented in the figure (see also figs. 252 and 253.). The cells in the central portion of the ovum were invested by a proper membrane (*e*), between which and the membrane *f* there was a fluid (pars. 338. 339. 342. 343. 360.), containing two or three minute cells which had escaped liquefaction (par. 350.). The cells immediately internal to the membrane *e* seemed to be

undergoing liquefaction. Internal to them was a delicate vesicle *c*, apparently the germinal vesicle enlarged to the diameter of about $\frac{1}{18}''$. This vesicle contained, on the inner surface of its membrane, cells of considerable size, apparently liquefying. These surrounded a layer of minuter ones, having their nuclei in some instances on one side; and these minuter cells seemed also to be circumscribed by a delicate membrane (par. 349 Note, 360.). In the most internal part there were two large cells (*bs*), corresponding to those occupying the centre of the ova figs. 187 and 191. These twin cells—the essential portion of the ovum, that is, the germ—were of about the same size ($\frac{1}{30}''$ in length) as those in fig. 191, but they were less transparent; a difference which perhaps arose from the outer portion of their nuclei having resolved itself into cells (see the explanation of fig. 192.), while another layer of the foundations of new cells, arisen in the interior (and presenting also the appearance of a nucleus) had succeeded it (par. 380.). (The ovum was surrounded by transparent fluid. Possibly this fluid arose from liquefaction of the tunica granulosa and retinacula). 100 diam.

PLATE XXV.

All the Figures are from the Rabbit (Lepus Cuniculus, LINN.).

Fig. 194. An ovum of eleven hours, found half-way between the infundibulum and the middle of the Fallopian tube, and measuring in diameter $\frac{1}{18}''$. It was taken from the same Rabbit as the ova in figs. 195 and 199. The central portion of this ovum differed from that of the ovum fig. 193. in the following respects; namely, the twin cells (*bs*)—constituting the germ—were somewhat larger, and no vesicle was seen corresponding in appearance to *c* in that figure. The nuclei of the cells which closely invested the germ, seemed to be situated (as in the ovum fig. 193.) on one side of their cells. 100 diam. (par. 380.)

Fig. 195. An ovum of eleven hours, found at two-thirds of the distance between the infundibulum and the middle of the Fallopian tube, and measuring in diameter $\frac{1}{18}''$. It was taken from the same Rabbit as the ova figs. 194 and 199. This ovum appeared to be in a state resembling that of the ovum fig. 193. The delicate vesicle *c*—apparently the enlarged germinal vesicle, now irregular in its form—measured in diameter $\frac{1}{18}''$. On the inner surface of the membrane of this vesicle were cells of considerable size, having minuter ones between them. (Two large cells—constituting the germ—occupied the most central part. They are not shown in the present figure, because of its exhibiting a superficial

view.) On the membrane *f* are represented a few of the cells of the tunica granulosa (*g*¹), which after fecundation become very much elongated, assume a club-like form, and are connected with the membrane *f* by their pointed extremities alone (par. 345.). The largest seen on this ovum measured $\frac{1}{4}$ ^m in length. (These cells in some instances contain a cell of considerable size, surrounded by dark globules, at their larger extremity. In other instances several cells are seen in their interior.) 100 diam.

Fig. 196. An ovum of (not less than) sixty-six hours (par. 366.) found in the uterus, and measuring in diameter $\frac{1}{3}$ ^m +. The outer surface of the membrane *f* ($\frac{1}{11}$ ^m —) was very rough; a state observed in all the ova (seven) found in this Rabbit. The chorion (*cho.*) had thickened, imbibed a large quantity of thick transparent fluid (*f*¹), and distended to the diameter above mentioned; but the essential portion of the ovum—the two elliptical cells (*bs*) in its centre—had advanced but little more than the corresponding part in the ovum fig. 194, of one-sixth the age; and still less than the corresponding part in the ova figs. 198 and 201. of only one-twelfth the age (par. 365.). (Six other ova were found in this Rabbit, namely, two in the uterus and four in the Fallopian tubes. These six were duly developed in the essential part (par. 367.). The inner surface of the now thickened chorion was seen in two ova from this Rabbit.) 100 diam. (par. 380.)

Fig. 197. An ovum of (not less than) sixty-two hours, found in the Fallopian tube, half-way between its middle and the uterus. It measured in diameter (as much as) $\frac{1}{3}$ ^m, the chorion (*cho.*) having imbibed fluid (*f*¹) and risen from the membrane *f*. The twin cells (*bs*) however—constituting the essential portion of the ovum—appeared less advanced than is generally the case at much earlier periods. With these twin cells there were smaller cells, presenting the same appearance as that described in the explanation of figs. 188 and 189; and the whole were circumscribed by a membrane (*e*), between which and the membrane *f* there was a space filled with transparent fluid. 100 diam.

Fig. 198. An ovarian ovum of (no more than) $5\frac{1}{2}$ hours, measuring in diameter $\frac{1}{3}$ ^m (par. 365.). It was taken from the same Rabbit as the ovum of fig. 201. The two elliptical cells (*bs*) in its centre, constituting the essential portion of the ovum—that is, the germ—were more advanced than those in the ovum fig. 196, of no less than twelve times the age (par. 366.). These twin cells were not very transparent, which was perhaps owing to the outer portion of each of their nuclei having resolved itself into cells, and to their being surrounded by many dark globules. The remaining portion of each nucleus contained a pellucid cavity, larger

than the corresponding cavity in figs. 193. 194. 196. The germinal vesicle (*c*) was still present, distended to the diameter of $\frac{1}{3}$ " (par. 351.), and nearly filled by the twin cells, or germ (*bs*). 100 diam.

Fig. 199. An ovum of eleven hours, found half-way between the infundibulum and the middle of the Fallopian tube, and measuring in diameter $\frac{1}{11}$ ". It was taken from the same Rabbit as the ova figs. 194 and 195. The membrane which in those ova circumscribed the most central portion, had disappeared in the ovum of the present figure, leaving the large twin cells (*bs*), surrounded by very minute dark cells (par. 351.). (There was a trace of investing membrane (*c*?) on the right side.) External to those minute cells were larger ones, apparently undergoing liquefaction. These were surrounded by a proper membrane (*e*), which had become very thin, and seemed about to disappear. Between this membrane and the membrane *f*, there was a space filled with transparent fluid. The nucleus in each of the large twin cells consisted of two parts,—an inner and an outer (pars. 360. 380.). In the centre there was a pellucid space (par. 348.). 100 diam.

Fig. 200. An ovum of thirteen hours found in the Fallopian tube at its middle part, and measuring in diameter $\frac{1}{13}$ " +. This ovum was taken from the same Rabbit as that in fig 193, from which it differed in the large twin cells (*bs*)—constituting the germ—having increased in size, and become filled with cells, or the foundations of cells, arranged in concentric layers (pars. 348. 380.). External to these large twin cells were minute dark cells; and these were surrounded by larger ones, undergoing liquefaction. The whole were invested by a membrane, between which and the membrane *f* there was a space filled with transparent fluid, and containing minute cells which had escaped liquefaction (par. 350.). These minute cells presented cells in their interior. (Cells were collecting around the membrane *f*, to form the chorion. These have not been represented in the figure). 100 diam.

Fig. 201. An ovarian ovum of (no more than) $5\frac{1}{2}$ hours, and measuring in diameter about $\frac{1}{13}$ ". The Graafian vesicle containing it was vascular, but not very large. This ovum was taken from the same Rabbit as the ova of figs. 169 and 198. Along with the large twin cells (*bs*), constituting the germ, were other cells of considerable size, destined probably to undergo liquefaction; the whole being surrounded by a proper membrane which was so large as to be in contact in the greatest part of its extent with the membrane *f*. 100 diam. (par. 360.)

Fig. 202. An ovum of (no less than) fifty-two hours, which had proceeded so far as into the uterus, though the large twin cells (*bs*), constituting the germ, were but little more advanced than those in the ovum fig. 195, of only

54 hours, and taken from the ovary. The chorion (*cho.*) had a diameter of $\frac{1}{8}$ ". The membrane *f* ($\frac{1}{16}$ "") was unusually thick. This ovum was taken from the same Rabbit as the ova in figs. 203 and 205. 100 diam.

Fig. 203. An ovum of no less than fifty-two hours, and measuring $\frac{1}{8}$ " found in the uterus with that in the preceding figure, and that in fig. 205. (See the remarks on development not keeping pace with locality and size, in the explanation of fig. 202.) The twin cells (*bs*, $\frac{1}{8}$ " in length), constituting the germ, though smaller than those in fig. 202, seemed on the point of being liberated by the liquefaction of the cells surrounding them, and that of an investing membrane. The nucleus in one of the twin cells appeared to be situated at the surface of that cell (par. 378.). 100 diam.

Fig. 204. An ovum of 24 hours, found in the Fallopian tube between its middle and the uterus. It measured in diameter about $\frac{1}{11}$ ". The incipient chorion (*cho.*) had begun to imbibe fluid and to rise from the membrane *f*. (Some of the cells entering into the formation of the chorion, which had not fully coalesced, were still visible; but they have not been represented in the figure.) The large twin cells (*bs*), constituting the germ, were remarkably pellucid, though on the point of being liberated by the liquefaction of the surrounding cells, and of a previously investing membrane. This ovum was taken from the same Rabbit as that in fig. 207. 100 diam.

Fig. 205. An ovum of fifty-two hours, found in the uterus with the ova in figs. 202 and 203. The chorion (*cho.*) had attained the diameter of $\frac{1}{8}$ "—, but the drawing was not taken until six days after death, during which time it is possible that fluid had been imbibed; though this is not usually the case. The membrane *f* had an ellipsoidal form. The large twin cells (*bs*) had been liberated by the liquefaction of a previously circumscribing membrane, but the remains of cells were visible around them, and also two cells nearly perfect and of considerable size. 100 diam.

PLATE XXVI.

All the Figures are from the Rabbit (Lepus Cuniculus, LINN.).

Fig. 206. An ovum of 23 hours, from the middle of the Fallopian tube, and measuring in diameter about $\frac{1}{13}$ ". It was taken from the same Rabbit as the ova figs. 208 and 209. The pellucid centre in each twin cell had increased considerably in size (par. 348.). The objects previously surrounding the twin cells having liquefied, the latter (*bs*) alone occupied the centre of the transparent fluid contained within the membrane *f*.

(par. 352.). There was present however a minute solitary cell, which had escaped liquefaction (par. 350.). 50 diam.

Fig. 207. An ovum of 24½ hours, found in the Fallopian tube, between its middle part and the uterus. It measured in diameter $\frac{1}{16}$ ". The twin cells (*bs*) which occupied its centre (par. 352.) were of unequal size, and filled with cells. Several of the latter, situated in the centre of each twin cell, were larger than the rest; but it was not easy to distinguish the two destined to survive the parent cell (see fig. 209.). The incipient chorion (*cho.*) had begun to imbibe fluid (*f*'), and to rise from the membrane *f*. It presented indistinctly such of the cells, entering into its formation, as had not fully coalesced. Some of these have been represented in the figure. This ovum was taken from the same Rabbit as that in fig. 204. 100 diam.

Fig. 208. An ovum of 23½ hours, found in the Fallopian tube, on the ovarian side of its middle part, and measuring in diameter $\frac{1}{16}$ ". This ovum was taken from the same Rabbit as the ova in figs. 206 and 209. It was not figured until *between seven and eight weeks* after death, having been preserved in the manner recommended in the "Second Series" of these Researches par. 313. The twin cells (*bs*) corresponding to those in the preceding figure (par. 352.) were, like them, of unequal size (par. 355. 356.) but considerably smaller. Their interior presented other cells, each of which had its nucleus. In the centre of the latter was a pellucid space. (On the membrane *f* were cells, collected to give origin to the chorion (par. 372.). These have not been represented in the figure.) 100 diam.

Fig. 209. An ovum of 23½ hours from the ovarian side of the middle of the Fallopian tube, and measuring in diameter $\frac{1}{16}$ ". It was taken from the same Rabbit as the ova in figs. 206 and 208. Twin cells, such as those in most of the figures from fig. 187 to fig. 208 inclusive, were now no longer seen (par. 352.), the number of cells present being four (*bs*). Thus two—and only two—of the cells with which each twin cell becomes filled, had survived their parent (twin) cell,—all the rest, as well as the membrane of the parent cell, having disappeared by liquefaction. (Two or three cells however of extreme minuteness had not yet disappeared (par. 350.). One of these is represented in the figure.) The four cells were not elliptical, as in the early state (see the corresponding objects with the twin cells of fig. 207.), but globular in-form (par. 355.). Two of them were larger than the other two; a difference perhaps referable to an inequality in the size of the parent cells (see figs. 207 and 208.) (par. 356.). The interior of the four cells resembled that of the two in fig. 206, except that in one the central pellucid space

had disappeared. They were very transparent, and their membranes had a high refracting power. 50 *diam.*

Fig. 210. An ovum of thirty-five hours, found in the Fallopian tube between its middle and the uterus. It measured in diameter about $\frac{1}{10}$ ". The four cells (*bs*) constituting the essential portion of the ovum—each measuring about $\frac{1}{11}$ "—unlike those in the preceding figure, were of equal size. They were globular, except that where in contact with one another, some degree of flattening had occurred; though this was scarcely (if at all) perceptible when they were first seen. In their transparency and the high refracting power of their membranes, they resembled the cells of the preceding figure. Their contents seemed more advanced. In all, the minute central pellucid space had disappeared. A larger space now presented itself, filled with transparent cells of considerable size, around which were very minute ones comparatively opaque (par. 353. 357.). The structure of all the cells contained within the four, appeared to be essentially the same as that of the cells represented in the preceding figures; and it is deserving of notice that the contained cells were not globular, like the parent cells, but elliptic in their form (par. 355.). 100 *diam.*

Fig. 211. An ovum of thirty-six hours, found in the Fallopian tube, and measuring in diameter $\frac{1}{8}$ ". It was taken from the same Rabbit as the ovum fig. 212, and the objects in figs. 213 A. and 213 B. In the centre of this ovum were five cells. Three of these, larger than the rest and globular, corresponded to three of the four in the preceding figure. The other two, smaller and elliptical, appeared to be a new generation that had been contained within a cell corresponding to the fourth of those in the preceding figure, the membrane of which had disappeared. The remaining three larger cells exhibited a generation of two cells (the intended successors of the parent cell), besides others of minuter size. (These minuter cells would have undergone liquefaction along with the membrane of the parent cell (par. 354.).) 100 *diam.*

Fig. 212. An ovum of thirty-six hours, found in the Fallopian tube, and measuring in diameter $\frac{1}{8}$ ". It was taken from the same Rabbit as the ovum in fig. 211, and the objects in figs. 213 A. and 213 B. Four cells—corresponding to those in fig. 210.—having each given origin in its interior to two (persistent cells), the number present in this ovum was eight (*bs*). These cells—originally elliptical (see the corresponding ones in fig. 211.)—were now globular, but flattened where in contact with one another. They were exceedingly transparent. Their membranes had a high refracting power, and they contained other cells. Among the latter, two were in most instances easily distinguishable by their central

situation and their greater size. These two constituted the essential portion of the contents of each parent cell. All the others, as well as the investing membranes, had been destined to disappear by liquefaction. Sixteen cells would thus have formed the succeeding set. The larger of the young cells presented irregularities in their membranes, as if thus prepared for rapid distention. Several minute cells, which had escaped liquefaction (par. 350.), were visible in the transparent fluid of the ovum. 100 *diam.*

Fig. 213 A. The germ in an ovum of thirty-six hours, found in the Fallopian tube, and measuring in diameter $\frac{1}{8}$ " . It was taken from the same Rabbit as the ova in the two preceding figures, and the object in fig. 213 B. This germ consisted of eight cells (par. 352.)—each about $\frac{1}{10}$ "—which were in a condition resembling that of the corresponding cells in fig. 212. They are here represented in outline only, to show the irregularity with which they are aggregated together. 100 *diam.*

Fig. 213 B. An outline representation of eight cells constituting the germ (par. 352.) in another ovum from the Rabbit which yielded figs. 211. 212. and 213 A. These cells corresponded in size and condition to those in the last figure, differing only in their mode of aggregation. 100 *diam.*

Fig. 214. The outline of cells constituting the germ in an ovum of $57\frac{1}{2}$ hours, found in the Fallopian tube, and measuring in diameter $\frac{1}{8}$ " . It was taken from the same Rabbit as the objects in figs 215 to 219. These cells varied in size from about $\frac{1}{10}$ " , and less, to $\frac{1}{10}$ " . (In another instance they measured $\frac{1}{10}$ " to $\frac{1}{10}$ " , that is, the germ was in a more advanced state). Some of the cells in this figure (fig. 214.) seemed to correspond to the cells in figs. 213 A. and 213 B; while others, of a smaller size, appeared to be part of a new set. And this is the more probable, from the whole number having exceeded eight. (See the explanation of figs. 211. 212. 213 A. 213 B.). 100 *diam.*

Fig. 215. Outline of cells constituting the germ in an ovum of $57\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{8}$ " , from the Fallopian tube. This ovum was taken from the same Rabbit as the objects in figs. 214. 216 to 219. The cells were rather more numerous than those in fig. 214, and the proportion of smaller ones had increased (par. 354.); denoting a more advanced state (see the mode of origin of new cells, in the explanation of many of the preceding figures). 100 *diam.*

Fig. 216. The same object on a smaller scale. The transparency in the centre of each cell was found to be referable to the presence there of cells of larger size than that of the cells in a more external situation. 50 *diam.* (par. 357.).

Fig. 217. One of the cells of the two preceding figures (see the explanation of fig. 216.). 100 *diam.*

- Fig. 218. Cells ($\frac{1}{40}'''$ to $\frac{1}{30}'''$) from the germ in an ovum of $57\frac{1}{2}$ hours, and $\frac{1}{8}'''$, from the Fallopian tube of the same Rabbit as the objects in figs. 214 to 217. 219. The central *contained* cells were larger than those in fig. 217, and between them were myriads of dark cells of immeasurable minuteness. 100 *diam.* (par. 357.)
- Fig. 219. A cell from a corresponding situation in another ovum of similar dimensions from the Fallopian tube of the same Rabbit. 100 *diam.*
- Fig. 220. A group of cells (the germ) in outline from an ovum of fifty-two hours, and measuring in diameter $\frac{1}{4}'''$. The ovum was taken from the same Rabbit as the ova in figs. 202. 203. 205; and like them had passed into the uterus. The cells represented in this figure were more numerous and smaller than those in fig. 215. They were globular in form, and of nearly equal size. 100 *diam.*
- Fig. 221. Cells from the group in the preceding figure, represented on a larger scale. They contained elliptic cells, in no small degree transparent, between which were dark cells of extreme minuteness. 300 *diam.* (par. 357.)
- Fig. 222. Cells from a group presenting the same general appearance as those in fig. 220, and from an ovum found in the uterus of the same Rabbit. Their form was globular. One of them was seen to contain two elliptic cells, having essentially the same appearance as some of those which in the explanations of preceding figures have been represented as the destined successors of perfect cells (par. 353.). 300 *diam.*

PLATE XXVII.

All the Figures are from the Rabbit (Lepus Cuniculus, LINN.).

- Fig. 223. Outline of cells grouped in a mulberry-like form (= the germ, $\frac{1}{30}'''$) in the centre of an ovum of $57\frac{1}{2}$ hours, and of $\frac{1}{4}'''$, found in the Fallopian tube between its middle and the uterus. (The objects in figs. 224 to 228, as well as the ovum fig. 233, were taken from the same Rabbit.) These cells were more numerous and smaller (about $\frac{1}{80}'''$) than those in fig. 215. They were globular in form. Within the group was seen an elliptic cell, which also is represented in the figure; its length equal to twice the diameter of one of the surrounding cells. (The nucleus of this elliptic cell is the rudimental embryo. This nucleus has not been represented in the figure.) 100 *diam.* (par. 359.)
- Fig. 224. Outline of a group of cells constituting the germ in another ovum of $57\frac{1}{2}$ hours, and of $\frac{1}{4}'''$, from the same Rabbit, and the same locality as the object in the preceding figure (see the explanation of the latter). 100 *diam.* (par. 359.)

- Fig. 225. Cell ($\frac{1}{10}$ " in length) contained within the group exhibited in the preceding figure. The interior having been very indistinctly seen, its precise condition could not be ascertained. The appearance of the nucleus (*bb*), however, was such as the figure represents. This nucleus is the rudimental embryo. It had a finely granular appearance, and contained a pellucid central cavity. 100 *diam.* (par. 359.)
- Fig. 226. Cell with its nucleus (*bb*)—the latter being the rudimental embryo—as seen in a situation corresponding to that of the object in the preceding figure (par. 359.). It was also observed in an ovum of the same Rabbit; the ovum being in a similar condition, and having the same size and local situation in the Fallopian tube. 100 *diam.*
- Fig. 227. Nucleus (rudimental embryo) of a cell such as that in the preceding figure, on a larger scale. It was elliptical in form (par. 359.). 300 *diam.*
- Fig. 228. Appearance of a cell with its nucleus corresponding to the objects in the three preceding figures, and taken from another ovum of the same Rabbit. The nucleus (rudimental embryo) *bb*, was at the surface of its cell (par. 359.). The ovum was of like dimensions ($\frac{1}{4}$ "), found in the same part of the Fallopian tube, and presented a similar condition. This figure does not represent particularly the interior of the cell, which could not be distinctly seen. 300 *diam.*
- Fig. 229. An ovum of $64\frac{1}{2}$ hours, and of $\frac{1}{4}$ " , found near the uterus in the Fallopian tube. The cells at the surface of the central group or germ (*bs*) were globular, or nearly so. Each of them presented a nucleus, which was not central but situated at the surface of the cell. These nuclei were yellowish-brown in colour, and appeared to consist of two parts; a free portion, composed of the foundations of new cells,—and a more central portion having a finely granular appearance. Within the latter was a point, in some instances dark, in others presenting the appearance of a pellucid cavity (par. 358.). (A larger elliptic cell—corresponding to that in fig. 223—was undoubtedly present, but could not be discerned.) 100 *diam.*
- Fig. 230. An ovum of sixty-two hours, and of $\frac{1}{4}$ " , found near the uterus in the Fallopian tube. The nuclei (of the cells in the group or germ, *bs*) apparently corresponding to the nuclei at the surface of the cells in the ovum of the preceding figure—had now passed into the interior. The outer portion of each nucleus—presenting in fig. 229. merely the foundations of future cells—had expanded into cells which filled its vesicle; the inner portion (of each nucleus)—finely granular in the ovum fig. 229.—was now seen to be composed of the foundations of new cells. The appearance around the pellucid centre was that of a dark ring (par. 358.).

(A central elliptic cell was undoubtedly present in the group, but could not be discerned.) 100 *diam.*

Fig. 231. An ovum from the same Rabbit as that in the preceding figure, found in the same part of the Fallopian tube, and of the same size ($\frac{1}{8}''$); but its thick transparent membrane (*f*) much more capacious. The cells of the central group or germ (*bs*) had ceased to present the remains of a nucleus (seen in the ovum fig. 230.), and in their interior were cells resembling those in figs. 218 and 221, but much more minute. 100 *diam.*

Fig. 232. An ovum of seventy-two hours, and of $\frac{1}{8}''$, from the uterine extremity of the Fallopian tube. The cells of the central group or germ (*bs*) were globular. This group seemed to consist of two portions—an inner and an outer. The inner portion contained an elliptic cell of the same kind as the cells in figs. 225, 226 and 228; but its interior was dark, apparently from the presence of globules in its fluid (par. 359.). The outer portion of the group appeared to be expanding from the inner portion, to line the membrane *f* (par. 361.). 100 *diam.*

Fig. 233. An ovum of $57\frac{1}{2}$ hours, and of $\frac{1}{8}''$ +, from the uterine extremity of the Fallopian tube, in the same Rabbit as the ova from which figs. 223 to 228. were taken, but in a state rather more advanced. In the mulberry-like object or germ (*bs*) there had commenced a process of distention which, if continued, would have brought most of its cells—together with the contained elliptic cell—into contact with the membrane *f*, at the same time that a cavity was forming in its interior (par. 362.). The elliptic cell (the nucleus (*bb*) of which is the rudimental embryo) was more pellucid (par. 359.) than that in fig. 232. 100 *diam.*

Fig. 234. An ovum of $76\frac{1}{2}$ hours, and of $\frac{1}{8}''$, from the uterus. The process mentioned in the explanation of fig. 233. had brought the outer portion of the mulberry-like germ (*bs*) into contact with the membrane *f*; and the contained elliptic cell into near approximation to the same. This elliptic cell (the nucleus (*bb*) of which is the rudimental embryo) was less pellucid than the corresponding cell in fig. 233, its fluid presenting a granular appearance. The membrane *f* was much less capacious than that in the preceding figure. 100 *diam.*

PLATE XXVIII.

All the Figures except those in the upper line are from the Rabbit (Lepus Cuniculus, LINN.).

Figs. 235 to 243. are copies of delineations given by SCHLEIDEN of some of the earliest appearances presented by the vegetable germ† (par. 399. 400.). It will be seen that SCHLEIDEN's "embryo" corresponds to that which in this memoir I have denominated the germ.

Fig. 235. "Embryonal extremity of the pollen-tube of *Linum pallescens* together with an adherent portion of embryo-sac [α]. The cell-forming process is incipient. At the upper part there is already a young cell with its cytoblast; and below it are several loosely floating cell-germs."

Figs. 236. 237. 238. 241. 242. "Formation of the embryo in *Oenothera crassipes*. α . Embryo-sac. β . Pollen-tube. γ . Embryo. δ . Germinal shoots (*punctum vegetationis*, WOLFF.). ϵ . Cotyledons."

Figs. 239. 240. "Early conditions of the embryo of *Potamogeton lucens*."

Fig. 243. "A later stage from *Potamogeton heterophyllus*. δ . Plumula. ϵ . Cotyledon still unenclosed."

Fig. 245. Cells of the tunica granulosa (part of the "disc" of BAER) of the form which they assume after the fecundation of the ovum,—the largest as much as $\frac{1}{30}$ " in length (par. 345.). α . One of these cells from a fecundated ovum still in the ovary. β , γ . Several of these cells from ova which had passed into the Fallopian tube (par. 394.). (See also figs. 173. 181. 195.) 300 diam. (par. 387.)

Fig. 246. Cells of the retinacula ovi (part of the "disc" of BAER) as strewn around an ovum of twelve hours, from the Fallopian tube. They contained each an object having a vesicular appearance, with dark globules scattered on its surface. These cells of the retinacula, it will be observed, had not undergone the same change in form as those of the tunica granulosa (fig. 245.). 300 diam.

Fig. 247. Cells of the retinacula ovi (part of the "disc" of BAER) as strewn around an ovum of seven hours, from the Fallopian tube. They each contained other cells, the number of the latter in some instances being only two (par. 394.). In some of these contained cells, the nucleus was situated at the surface of the cell. 300 diam.

Fig. 248. Epithelium-cells from the fimbriated portion of the Fallopian tube of a Rabbit killed in the state of heat. They contained other cells, and one of them a central pellucid space. $\frac{1}{30}$ " And upwards (par. 394.).

† Fig. 235. is taken from MÜLLER's Archiv, 1838, Heft. II. Tab. III. fig. 17; and figs. 236 to 242, from WIEGMANN's Archiv, 1837, viertes Heft, Tab. VII. figs. 14. 15, figs. 6. 7. 16. 17, and fig. 8.

Fig. 249. Another form of epithelium-cells from the Fallopian tube of the same Rabbit which yielded the objects in the preceding figure. These cells also contained other cells. $\frac{1}{300}$ ''' And upwards (par. 394.).

Fig. 250. Epithelium-cells from the Fallopian tube of a Rabbit killed thirteen hours *post coitum*. They had become by pressure polyhedral. Length about $\frac{1}{100}$ ''' . They were filled with minuter cells. 300 *diam.* (par. 394.)

Fig. 251. Epithelium-cells from the Fallopian tube of the Rabbit which yielded figs. 248 and 249. They all contained minuter cells (par. 394.), and some of them spherical pellucid spaces, which in certain of those more advanced and carrying cilia had become elongated, in others were less distinct, and in some could not be discerned. α . $\frac{1}{300}$ ''' , β . $\frac{1}{100}$ ''' , γ . $\frac{1}{50}$ ''' .

Fig. 252. α . Cells collected together on the membrane *f* in an ovum of eleven hours, and of $\frac{1}{11}$ ''' —, from the middle of the Fallopian tube. The cells presented processes which had interlaced, and spherical pellucid objects in the centre. These cells by coalescing give origin to the chorion. β . Some of the same cells, which had a more superficial situation on this ovum (see also fig. 193.) (par. 373.).

Fig. 253. α . Cells collected together on the membrane *f*, and destined to give origin to the chorion, in an ovum of fourteen hours, and of $\frac{1}{11}$ ''' +, from the middle of the Fallopian tube. The processes (interlacing in fig. 252.) had become less distinct; and the pellucid central objects had in many instances undergone a change in form, and taken that of the containing cell. β . Some of the same cells as strewn around the ovum (see also fig. 185.) (par. 372.).

Additional Observations.

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431. Should the facts made known in the foregoing memoir regarding the essential portion of the mammiferous ovum be confirmed, it will of course be inferred that the same changes take place, and for the same purpose, in other ova. Having however been so fortunate as to discover that such really is the case, I think it proper to record my further observations; more especially as some of them happen to have been made on ova which, when compared with the ovum of Mammalia, seem at first sight to present an important difference.

432. The principal observations hitherto published on the contents of the unfecundated germinal vesicle throughout the animal kingdom, were made by Professor RUDOLPH WAGNER†, to whom we are indebted for the discovery of the germinal spot. I am truly glad that it has fallen to my lot, as I venture to believe, to show the importance of this discovery, which has been questioned.

433. In the ovum of some animals the spot is single,—in that of others there are many spots; this being the apparent difference above referred to (par. 431.). R. WAGNER observed that the ova of certain animals in which originally there is only one spot, at a later period present a number; and he conjectured that this might be referable to a division of the primary spot into several parts‡. It will be seen from what takes place in the mammiferous ovum, that this conjecture was very near the truth; and facts about to be made known, will serve to explain another observation of the same physiologist, namely, that the number of spots in some instances increases as the ovum ripens.

434. "In Birds," says WAGNER, "the germinal vesicle has always a germ-nucleus [germinal spot], which often forms a tolerably compact mass of finer molecules, but frequently consists of a very transparent and delicate tissue, and may thus be easily overlooked§." In scaled Amphibia the germinal spot is "at first single, but dissolves into several scattered points or globules, which adhere to the inner surface of the germinal vesicle||." In naked Amphibia, "instead of a single germ-nucleus or spot, there are always—even in the very youngest ova—several shining globules having a high refracting power. In maturer ova these become more numerous, but they are relatively and absolutely smaller, and often pressed together, being everywhere situated—in general but slightly adherent—on the inner surface of the germinal vesicle¶." The same author found the contents of the germinal vesicle in cartilagi-

† See the great work of WAGNER, "Prodromus Historiæ Generationis," before referred to in this memoir.

‡ Lehrbuch der Physiologie, I., pp. 57, 58. § A. Encykl. d. W. u. K. Erste Section xxxii. "Ei," p. 3.

|| Ibid. p. 3.

¶ "Ei," p. 3.

nous Fishes to resemble the corresponding parts in Birds. His description of these parts in osseous Fishes, is essentially the same as that of the corresponding parts in naked Amphibia.

435. On examining the germinal vesicle in a Bird†, in one of the Batrachian Reptiles‡, and in several osseous Fishes§, I find it in many instances to contain—not merely spots but—*nucleated cells*; the “shining globules” in naked Amphibia described by WAGNER as having a high refracting power, being obviously the nuclei of these cells. We thus find that, as in the mammiferous ovum at a certain period, the germinal vesicle of these animals contains cells.

436. But this is not all. When more closely examined, and especially after the addition of dilute spirit, many of the objects in question present an analogy still more striking, and one indeed which it is not presumption to consider perfect. Not merely does the germinal vesicle contain nucleated cells, but these cells are arranged in layers around a point which appears to be situated at the periphery of the vesicle; the layers nearest to this point being opaker than the rest. The interior of many of the contained cells also presents an appearance, indicating a process of the same kind as that implied by the state of the germinal vesicle or parent cell. In short, the contents of the germinal vesicle in Birds, Batrachian Reptiles, and osseous Fishes are often found to be in a condition so nearly resembling that of the contents of the mature germinal vesicle in Mammalia, that a description of the one would be almost applicable to the other; the difference consisting merely in the period at which the nucleus of the germinal vesicle resolves itself into incipient cells.

437. The analogy extends also to the substance surrounding the germinal vesicle, which is seen to consist of nucleated cells.

438. It is extremely satisfactory to be thus enabled to refer to ova which are so easily obtained, for a confirmation of my observations on the mammiferous ovum.

439. I have already alluded (par. 327 *Note*.) to a conjecture of Professor R. WAGNER, that the presence of “minute scattered globules” in the riper ova of certain animals|| may be referable to a division of the primary “spot;” which conjecture I think it will be seen was very near the truth. A previous suggestion, however, of the same author, it will be obvious, does not accord with my experience. He says with reference to ova of the naked Amphibia: “It is perhaps not unimportant for future investigations, if the views of SCHWANN should be confirmed, that sometimes in minute and unriper ova***one spot is remarkable from its being larger and opaker than the rest. It is perhaps the nucleus of the cell, while the others belong to the contents of the cell [zelleninhalt]¶.” I do not think that the smaller “spots” just mentioned belong to the “zelleninhalt” or “contents of the cell,” in the sense, in which this term is used in

† The Pigeon (*Columba domestica*, LINN.).

‡ The Frog (*Rana esculenta*, LINN.).

§ Among which were the Turbot and Plaice (*Pleur. maximus* and *Platessa*, LINN.).

|| Squamous Amphibia and cartilaginous Fishes.

¶ “Ei,” p. 3.

the doctrine of "cells," namely, to denote a substance which is supposed to have arisen independently of the nucleus. From my observations, the smaller "spots" in the *naked Amphibia* and *osseous Fishes* also, are produced by a resolution of the nucleus; and the "larger and opaker" "spot" seen by WAGNER may have been, not as he conjectures the entire nucleus of the cell, but the central, unresolved, and most important portion of that nucleus.—As to the "zelleninhalt" or "contents of the cell," I may here remark that I do not recollect to have met with such a substance in a solid state, in which there was not every reason to believe that it had arisen from the resolution of more or less of a nucleus, or from that of the nuclei into which a nucleus becomes resolved†.

440. The following is the experience of R. WAGNER on the germinal spot in the ovum of some of the Invertebrata. If, in the perusal of it, my observations on the corresponding part in the mammiferous ovum be borne in mind, I think it will be found that here also the analogy is not wanting.

441. In Insects, "the germinal spot—or opaker portion of the contents of the germinal vesicle—in some instances appears as a single, dark, granular, spherical mass, which admits of being separated with the compressorium into different forms,***or it is an accumulation of minute isolated globules;—in some instances also, it is a delicate, finely granular, almost membranous-like layer, near which there sometimes appear one or more dark spots; or finally (in rare cases) there are present scattered germinal spots, as in *osseous Fishes* and *naked Amphibia*‡." In the *Arachnida*, "the germinal spot***sometimes appears as though it were an accumulation of grains, inclosed by a membrane; sometimes there are several accumulations of granules, and among them one or two larger spots§." In the *Crustacea*, "the germ-nucleus or spot is always present, and of manifold forms." It is sometimes "a large heap of grains"—in some instances "circumscribed by a membrane, rarely with some accessory spots"—in others, "an accumulation of twelve and more grains§." In *Astacus* and *Gammarus*, the same naturalist always found "minute spots on the inner surface of the germinal vesicle, as in *Batrachians* and *osseous Fishes*§;" which spots he de-

† The discoid objects constantly referred to in some parts of the foregoing paper, we have seen to pass into cells of the same form; and it is not easy to say where the disc terminates and the cell begins: so that in many instances I have been obliged to use almost indiscriminately the terms "disc" and "cell." I do not recollect indeed to have observed any of these discoid objects in the transition state in question, in which there was not an appearance in the most superficial part of the interior, denoting decomposition of the outer portion of the disc. So uniformly has this been met with, that I am ready to suppose the formation of the cell-membrane to be connected with such decomposition, or perhaps dependent on it. VALENTIN, though agreeing with other authors as to the order of formation of the parts connected with the cell, mentions not having observed the formation of the cell-wall to have taken place until the nucleus was everywhere surrounded with the future "zelleninhalt" or contents of the cell (*Repertorium*, 1839. II., p. 285.). Did not the "zelleninhalt," seen by VALENTIN, consist of the outer portion of the previous "cytoblast?"

‡ "Ei," p. 4.

§ *Ibid.* p. 4.

scribes as being "originally scattered†." In the Annelida, "the germinal vesicle is furnished with a minute, opaque, single germ-nucleus or spot, which sometimes presents an accumulation of grains. In *Cleptine bioculata****the germinal vesicle presents numerous, minute, pale, scattered spots, as in the Batrachians†." In some of the Mollusca, "the germ-nucleus or spot is usually a single, opaque mass, which is sometimes granular, and in some instances surrounded by minuter appendages, or has the appearance of being invested by a membrane§."

442. With reference to ova in general at the period of their ripening, R. WAGNER remarks: "In the contents of the germinal vesicle, hitherto transparent, there takes place a coagulation; new globules present themselves near the single or manifold germinal spot (which is to be considered as the nucleus of the germinal vesicle),—or there are formed accumulations of granulated masses which sometimes constitute even membrane-like layers, as in many Insects. The germinal spot disappears as a single nucleus, or is no longer to be found among the other grains.***As soon as the ova have left the ovary***the germinal vesicle is no longer to be found. It has suddenly or at least rapidly disappeared. Whether it suddenly bursts, or quickly collapses, is doubtful. The latter, from observations on the ova of Frogs and other animals, appears to me the more probable. The thinly fluid contents are observed to diminish in quantity, while there arise more solid granular coagulations||."

443. A spot was described in my "First Series"¶ on the inner surface of the membrana vitelli in the ovum of the Frog. In the course of recent examinations it has seemed to me that the black layer—known to form at the periphery of the yolk in this ovum—comes into view as the spot in question disappears. The spot is composed of flat, elliptic objects such as those which become resolved into minuter objects, of the same kind, in the substance surrounding the germinal vesicle in the mammiferous ovum††.

† Is there not an earlier period in these, as probably in all other ova, when there is present only one spot or nucleus?

‡ "Ei," p. 5.

§ Ibid.

|| "Ei," pp. 7. 8.

¶ Philosophical Transactions, 1838, Part II., p. 313. par. 40. Plate VI. fig. 28 d'.

†† When I communicated my last memoir ("Second Series," *I. c.*, par. 292. Note), the presence of this spot, in connexion with the new doctrine of "cells," seemed to require a modification of some of the conclusions in my "First Series," as to the order of formation of the several parts of which the ovum is composed. For, presuming the spot in question to be the nucleus of a cell—and (following SCHLIDEN's views) necessarily existing before the membrane of its cell—I stated that if such spot were present in the corresponding membrane of other ova, the formation of this membrane is doubtless earlier than that of the germinal vesicle itself.—I have now to add, that later observations induce me to believe that the spot in question does not correspond to the nucleus of a cell, but seems (as above) to denote the commencement of the formation of the black layer, such formation appearing to begin in one of the discs by which the germinal vesicle is surrounded; which disc then presents the appearance of a lenticular and usually elliptic spot.—The existence of this spot, therefore, does not affect my conclusions as to the order of formation of the several parts of the ovum; nor do I see that the doctrine of cells—modified as it must be by the facts made known in this memoir—affects those conclusions.

XXIV. *On the Corpuscles of the Blood.* By MARTIN BARRY, M.D., F.R.S., F.R.S.E.,
&c.

Received May 14,—Read June 4, 1840.

THE principal facts recorded in the following memoir were incidentally observed during the researches which formed the subject of my last communication†.

(The measurements in this paper, as in former ones, are stated in fractions of a Paris line, and thus expressed (^m)).

Progressive Division of the Blood-disc into Globules.

1. My examinations of the internal generative organs in the Rabbit have generally been made at a period when these parts were found more or less highly vascular. In fluid collected at this period from the surface of the ovary, from the fimbriated portion of the Fallopian tube, or from the infundibulum, it is usual to find a large quantity of corpuscles of the blood, which are present also in other parts of the oviduct. It thus appears that blood-corpuscles become extravasated in these parts at the period in question.

2. Many of these corpuscles present an appearance (Plate XXIX. figs. 1. 2. α) resembling that generally exhibited by the corpuscles in blood obtained by venesection. But a very large number are in altered states, an idea of which may be obtained from such of the objects in fig. 2. as are not distinguished by a letter.

3. More particularly examined, and in considerable number, the objects in question are found to present every shade of transition between the unaltered blood-corpuscle Plate XXIX. fig. 1. α , and the mass of distinct globules, fig. 2. δ . This will be seen on inspecting successively α , β , γ , of fig. 1, and then the numerous unmarked objects in fig. 2; beginning in the latter figure with those most resembling γ of fig. 1‡.

4. Several of the appearances in the figures just referred to, will be recognized by those who have watched blood-corpuscles in the microscope, when undergoing the first alterations in their form. I find, however, that the presence of blood-corpuscles in these altered states, in the fluid above mentioned, is constant,—and this too when the parts are examined as early as a few minutes after the animal has been killed,—when therefore they are still warm. And what is more, in a portion of the fimbriated

† Researches in Embryology, Third Series: A Contribution to the Physiology of Cells. Philosophical Transactions, Part II., 1840, p. 529, that is, the present volume.

‡ It is perhaps deserving of notice, that a central pellucid cavity similar to that in other objects of this figure, was not observed in the centre of the mass of globules δ . Does it disappear as these globules form?

extremity of the Fallopian tube, removed immediately after death, I have seen blood-corpuscles in some of the altered states still circulating, or at least not quite at rest, within a blood-vessel. Hence it seems probable that the changes in question take place within the living body.

5. The altered blood-corpuscles just referred to, at first retain their flattened form, as will be seen on reference to fig. 2, which exhibits a few of them on their edges, or nearly so.—It may here be stated that my observations corroborate those of previous observers, that the blood-corpuscles in the Mammalia are biconcave; yet with HODGKIN and LISTER†, I find them in Man to be rounded at the edges‡, and not cut off abruptly as they have been described§.

6. If the elliptic discs surrounding the germinal vesicle in a number of the figures of my "Third Series" be examined, they will be found in many respects to resemble the corpuscle of the blood, which—it will be recollected—in some of the Vertebrata has an elliptic form||. Now all the cells referred to in that Series, were described as presenting in an incipient state essentially the same appearance as the objects surrounding the germinal vesicle. They were shown to exhibit a pellucid space surrounded by a finely granular substance.

7. I am reminded of this state by the appearance of the unaltered blood-disc. And certainly the division into globules to which we have now traced the blood-disc, is very far from lessening the resemblance.

8. A reference is here necessary to my "Third Series" on Embryology, l. c., Plate XXIV. fig. 192. The object there seen consisted of a central pellucid space surrounded by one layer of what later stages showed to have been the foundations of cells. And if that object be compared with some of the altered blood-corpuscles in Plate XXIX. fig. 2. of the present paper, the appearance will be found to be essentially the same in both. Whether the globules into which the blood-disc resolves itself, are the foundations of new corpuscles of the blood, I do not know; but it is certainly not unimportant that there exists so perfect a resemblance, in appearance, between two objects, the nature of one of which has been ascertained¶.

† Translation of Dr. EDWARDS on the influence of physical agents on Life, Appendix, p. 431.

‡ I am indebted to the kindness of Professor RUDOLPH WAGNER for some plates, intended to accompany the second part of his "Lehrbuch der Physiologie;" one of which, Tab. XIII., I observe contains figures of mammiferous blood-discs, rounded at the edges; as does also his work, "Beiträge zur vergleichenden Physiologie. Heft II. 1838."

§ MÜLLER's Physiology, translated by Dr. BALY, Part I., 1837. p. 99. fig. 1.

|| The blood-corpuscles of some of the Amphibia present a curious resemblance to many of the elliptic discs figured in my "Third Series" on Embryology, in the present volume.

¶ The condition of the blood-corpuscles above described (Plate XXIX. figs. 1 and 2.) is obviously that which was particularly observed, not only in very different mammals but also in one of the Amphibia, by Professor OWEN (Med. Gaz. Nov. 13, 1839.). This eminent anatomist and physiologist has shown that the appearance in question presents itself in blood so recently drawn, that it cannot be considered as the effect of manipulation. It suggested to him "the idea that the blood-disc was undergoing a spontaneous sub-division into smaller vesicles; and although," he proceeds, "my observations are not at present sufficiently numerous to warrant the

9. The appearance of the globules in question suggests the idea that they may be identical with the so-called "lymph-granules," or blood-corpuscles of the "second form†."

hypothesis that the development of smaller vesicles within itself is a normal property of the ordinary coloured vesicle or blood-disc, yet the obscurity which still hangs over the origin and reproduction of the blood-discs, and the unexpected constancy of the granulated form in a greater or less proportion of them, while recent, and floating in the serum, in the different species examined, makes me unwilling to suppress an idea, naturally arising out of such observations, and likely to be suggestive of examination of the same appearance by other microscopical observers." At the time of recording the above observations, I was not aware that such an idea had been published. I shall be glad if those observations are such as to confirm it. There is one fact mentioned by OWEN which I think particularly deserving of attention here. In describing the blood of a cold-blooded animal—the *Monitor*—he remarks, "many of the discs had the marginal contour slightly crenate, with lines converging to the nucleus."—The appearance of the blood-disc when undergoing the changes which we have seen to terminate in a separation into globules, seems to have been noticed by several observers; among whom may be mentioned HEWSON and FALCONAR, and more recently HODGKIN and LISTER. It is not easy, indeed, to understand how the sharp-sighted LEEUWENHOEK should have suspected the "globules" of the blood to be made of six lesser globules, unless he had seen some of the appearances in question. Some late remarks by GULLIVER, to whom we are indebted for a vast number of observations on the size of the blood-discs in different animals, show that this gentleman had long been in the habit of observing these appearances, and that he deemed them of importance. He mentions having observed the "granulated particles in great numbers, both in their serum and in a dry state***in blood examined immediately after it was obtained from the veins of various animals, particularly young kittens. The nature of these particles," he continues, "is worthy of further and special inquiry. They are to be found plentifully during digestion; but, in their deep red colour and chemical properties, they differ remarkably from the granules observed in the chyle" (Lond. and Edinb. Phil. Mag. Jan. 1840.). The same author subsequently remarks, "The granulated particles are almost uniformly smaller than the common discs, and it is not improbable that some of the former may be produced by the irregular shrinking of the latter. In some instances I could not detect any of the granulated corpuscles in the blood immediately after it was taken from the animal, although they were to be seen abundantly after a few hours exposure in the serum to the atmosphere, the temperature ranging between 45° and 50°. In one observation some of the extremely minute spherules which are not uncommon in the blood, were observed to attach themselves to a few of the smaller discs, so as to produce the granulated appearance" (Lond. and Edinb. Phil. Mag. Feb. 1840, p. 107.). It would thus seem, however, that the idea of a division of the blood-disc had not occurred to the author now quoted.

† On the subject of these "lymph-granules" or corpuscles of the "second form," many valuable observations have been communicated by R. WAGNER, from whose work—*Beiträge zur vergleichenden Physiologie*, Heft II. 1838,—I make the following extracts, in which will be found remarks that appear to me to be favorable to the suggestion above offered, on the possible identity of the globules into which the blood-corpuscle divides, with corpuscles of the "second form."

"In the blood of Birds, Amphibia, and Fishes, there is present in greater or less quantity a second form of corpuscles, which at first sight may be distinguished from the real blood-corpuscles, and to which the attention of physiologists was recently directed by JOHANN MÜLLER. (BURDACH'S Physiologie, iv. S. 108.) [As Dr. BALY very properly remarks, HEWSON probably saw the same objects, considering them the nuclei of the blood-discs, (Experimental Inquiries, &c. Part III. p. 133.) HODGKIN and LISTER appear also to have seen them, (l. c., p. 437.)] They have since been seen and closely investigated by many observers, and I long ago considered them at length. (HICKER'S Literarische Annalen, 1834, Februarheft.) On the universal presence, the relative quantity, and the size of these granules, we have not yet any complete investigations.***In the arterial blood of a

10. The objects ϵ in Plate XXIX. fig. 2. were of a reddish colour, but larger than blood-corpuscles. They also presented distinctly a membrane at the surface, and contained globules or discs (each of which had its pellucid centre) surrounding a common pellucid space. One of the objects ϵ was elliptical, the others appeared more or less globular in form.

11. It is still a question with some, whether the blood-corpuscles in the embryo are formed out of granules of the yelk. My Second Series on Embryology† will I think have served to decide this question; for it was there shown that in the mammiferous ovum there exist no yelk-granules which can be so transformed; the ovum being filled with colourless transparent fluid.

Rapid and incessant Changes in the Form of altered Blood-corpuscles.

12. In Plate XXIX. figs. 3, 4, 5, are seen the momentary forms of objects which I observed in fluid collected on the fimbriated portion of the Fallopian tube, at the periods respectively of 5, 13, and $5\frac{1}{2}$ hours *post coitum*. These objects were altered corpuscles of the blood. Fig. 3. presents a gradual transition from the blood-corpuscles in fig. 1, to objects which in the absence of such connecting links would scarcely have been recognized as such.

13. These altered blood-corpuscles (figs. 3, 4, 5.) were in motion; rarely exhibiting a change of place, but presenting a rapid and incessant change of form. I have had many opportunities for observing these motions, which are often such as to be comparable to the writhings of an animal in pain. Sometimes one of the objects in question assumes in a twinkling an hour-glass shape, as if about to separate into two portions; but as quickly regains its previous form, or assumes a new figure. The condition, however, is by no means one of alternate rest and motion. The motion, as already said, is incessant, and so rapid that it is extremely difficult to catch and deli-

young man of nineteen years, from whom blood was taken in Bronchitis; I found, besides the regular concave blood-corpuscles (averaging in diameter $\frac{1}{100}''$), distinctly spherical finely granulated globules of $\frac{1}{100}'''$ to $\frac{1}{100}''$, in appearance entirely corresponding to the second form of corpuscles, which are so easily demonstrable for instance in the blood of Frogs. Quite similar globules, though in more sparing quantity, I found in my own blood after venesection in consequence of inflammation.***I have since always found these corpuscles in drawn blood.***They appear to stand in exact relation to the size of the blood-corpuscles of the animal.***They, however, vary much more in size than the [true] blood-corpuscles.***With respect to the form,***I hold them indeed to be globular, but perhaps globules pressed somewhat flat.***They are distinguishable from the other blood-corpuscles, also: 1. by being colourless; 2. by a certain lustre, and the property of strongly refracting light; 3. by their peculiarly granular appearance, so that they might be taken for aggregates of globules (nevertheless it appears to me that they are granular only at the surface)." R. WAGNER then shows that the number of these corpuscles of the "second form" is greater in animals well-fed, and he mentions an instance in which they greatly increased after the blood had stood for two hours. R. WAGNER, Beiträge zur vergl. Phys. II. pp. 19—48.

† Philosophical Transactions, 1839, Part II. p. 307.

neate any of the forms which arise. Sometimes the corpuscles suddenly become inverted; and I have observed certain of them (fig. 3. β .) which seemed to be horizontally revolving. The field of view in some instances is covered with these moving particles.

14. I have seen these motions of the altered blood-discs when the latter were covered,—in some instances with glass, in others with mica,—and also when uncovered; and I have observed them as late as two hours and a half after death, as in fig. 3†. They soon cease after removal of the fluid to the microscope. The cessation is, however, very gradual; rapid change of form passing into gentle undulations; and these being succeeded by an alternation of rest and motion.

15. In fig. 4. I have delineated the forms retained in one instance by four of the corpuscles in question after their motions had entirely ceased. The pellucid centres, such as those seen in the objects of this figure, are often not distinctly visible while the motions are proceeding. Sometimes, however, during rapid motion, I have observed appearances like those in fig. 5; the contained pellucid fluid being now central (α), then on one side (β), or divided into several parts (γ).

16. The addition of cold water does not immediately arrest the motions. I could not discern any in the remains of the corpuscles after dilute acetic acid had been added.

17. I have seen these motions of the altered blood-corpuscles, in fluid collected on the fimbriated portion of the Fallopian tube, in a Rabbit which had not had connexion with the male, but was killed during the rut.

18. They seem to be attended in some instances with a considerable increase in the size of the corpuscle (fig. 3. γ .)‡.

19. Should these facts be thought to confirm the opinion of HUNTER, that the Blood "has life within itself," or "acquires it in the act of forming organic bodies," because its corpuscles in certain altered states exhibit "vital action," still his assertion that "the red globules" are the least important part of the blood, will appear to have no just foundation§.

† The examinations were usually commenced a few minutes after the animal had been killed.

‡ Reference is made by R. WAGNER to a statement of CZERMAC with which I am unacquainted. "Vital motions," says WAGNER, "such as those which CZERMAC maintains that he has observed (for instance in Blood from the gills of the Proteus), I have never seen; and this assertion certainly rests on an illusion occasioned by the phenomenon which is produced by ciliary motion." WAGNER supposes the motions seen by CZERMAC to have been caused by portions of the gills, the cilia of which set the escaped corpuscles of the Blood in motion (Beiträge zur vergl. Phys. Heft II. pp. 17, 18.).

§ As stated in the London and Edinburgh Philosophical Magazine for August, 1840, p. 157, my later observations induce me to believe that the rapid and incessant changes in form of altered blood-corpuscles, described in pars 12 to 18. of this memoir, are caused by contiguous cilia; though I have not yet succeeded in demonstrating the latter. It is certainly a remarkable state of the blood-disc, however, which admits of such changes in its form.—November 1840.

The Chorion formed of Cells derived from Corpuscles of the Blood.

20. When the ovum is sought for in the Fallopian tube in the manner recommended in my "Second Series" on Embryology (*l. c.*, par. 313.), it is very common to find, in the mucus, patches of more or less altered blood-corpuscles. Plate XXIX. fig. 6. presents a minute portion of one of these patches, from the Fallopian tube of a Rabbit killed twelve hours *post coitum*. Many of the corpuscles (α), still flat, had undergone little change besides being pressed together into six-sided figures. Others (β) had become orange-shaped, highly refracted light, and presented in their interior a brilliant object, which in some instances (γ) was seen to be not central, but situated on one side. The diameter of the objects β was in general rather less than that of the unchanged corpuscles α . Whether this difference in diameter was referable to the change from a flattened to the more globular form, which would perhaps be sufficient to explain it $\dagger$,—or whether an outer covering (present in α) had disappeared in β ,—I do not know; but the occasional presence of extremely minute granules or globules around such objects (ϵ), leads me to think it very possible that the disappearance in question does take place. If the figure be closely examined, and more particularly on the left side, transition states will be observed between the unaltered corpuscles α , and the cell (for such it may now be termed) β . The figure presents several cells (δ) in which a further change had taken place. They had become elliptical.

21. In Plate XXIX. fig. 7. are seen blood-corpuscles, now cells, from the Fallopian tube of a Rabbit killed fourteen hours *post coitum*. Some of these (δ) were in a state resembling that of δ in fig. 6. Others had enlarged, and presented processes or arms. When viewed singly and highly magnified, such objects appear yellowish; an accumulation of them, seen by the unassisted eye, or with a low magnifying power, is blood-red.

22. I formerly showed $\ddagger$ that during the passage of the ovum through the Fallopian tube, there rises from the thick transparent membrane (f) a thinner membrane. The latter was traced from stage to stage up to the period when villi form upon it, and thus ascertained to be the incipient chorion.

23. In a later paper $\S$ I stated that the thin membrane in question (the incipient chorion) is formed of cells, and that these are not cells of the ovarian so-called "disc," but newly-arisen objects, the nature of which more particularly would be made known in a future paper.

24. If now my last memoir be referred to $\S$, it will be found that the cells represented in Plate XXVIII. fig. 252 and 253. of that memoir, as forming the incipient chorion, have the same appearance as some of those in Plate XXIX. fig. 7. of the

$\dagger$ It did not escape the notice of Huxson, that the diameters of the red particles of human blood diminish from the particles becoming spherical, *l. c.*, pp. 18, 19.

$\ddagger$ Researches in Embryology, Second Series, *l. c.*, pars. 172. 222. Plate VI. fig. 104. α and β .

$\S$ Researches in Embryology, Third Series, *l. c.*, pars. 370 to 373.

present paper. And I confirm the statements made on that occasion; namely, that the cells send out processes or arms which interlace; that the contained pellucid object seems to enter into the processes or arms; that it is by a coalescence of the cells that the incipient chorion is formed; that the additions of cells appear to be continued up to the period when villi are produced; and that the villi themselves are probably formed out of the same kind of cells. It remains to add, that the cells in question, delineated in that paper, not merely have the same appearance, but are identical with those in Plate XXIX. fig. 7. of the present memoir: in other words, that the chorion is formed of cells which are altered corpuscles of the blood.

25. In Plate XXIX. fig. 8. are seen some of the very earliest traces of the formation of the chorion. The cells (g^1) of the tunica granulosa were described on a former occasion†, as becoming club-shaped and connected with the membrane f by their pointed extremities alone, after the fecundation of the ovum. Such is the form and position of the cells g^1 exhibited, for the most part in outline, in this figure. One purpose answered by the changes just mentioned as presented by the cells g^1 , seems to be that blood-corpuscles (*cho.*) find their way between them, and have space for applying themselves to the membrane f , while this membrane continues to be protected by those cells‡. In fig. 8. several blood-corpuscles (*cho.*) are seen to have occupied the latter situation, where, in some instances, they appear to effect the alterations in their form above described§. Three of them, it will be observed, had become cells, and two were in the same stage as some of those in fig. 7, having begun to send out processes or arms||.

26. For the announcement that the chorion is formed by corpuscles of the Blood, physiologists, I apprehend, are not prepared; it being the generally received opinion that the formation and the nourishment of organs are effected through its fluid part¶. But the next section records facts which, if established by future observation, involve more important consequences.

Muscular Fibre formed of Cells derived from Corpuscles of the Blood.

27. The latest researches, which have been published, on the mode of origin of muscle, are I believe those of VALENTIN and SCHWANN.

† "Third Series," *J. c.*, par. 345.

‡ Which also may afford fluid for the imbibition of the chorion. The protection above referred to is possibly essential during the transit of the ovum into the Fallopian tube.

§ In other instances those alterations occur before the blood-corpuscles take their places on the ovum.

|| In Insects, a structure supposed to be analogous to the chorion of Mammalia, is often found to present itself in the ovary, and it "not rarely exhibits an elegant delineation consisting of flat coalesced cells." (R. WAGNER, *A. Encycl. d. W. u. K. Erste Section*, XXXII. "Ei," p. 4.)

¶ An eminent physiologist, however, has recently remarked: "What becomes of the blood-corpuscles,—whether they are transformed,—whether entirely or in part they are here and there deposited,—whether they dissolve, &c. has not been ascertained; we are reduced to mere hypotheses." (R. WAGNER, *Beiträge zur vergl. Phys. H. II. S. 54.*

28. "Muscular fibre," says VALENTIN, "arises***out of the jelly-like formative mass ***in the following manner: Long before separate muscular fibres are perceived, the globules of the primitive mass are seen arranged in longitudinal lines.***The granules ["globules"] now appear to approach one another, and in single places entirely—in others only on one side—to coalesce and unite into one transparent mass. By this means there arise threads, which in many places have a necklace-like appearance; in others are less distinctly notched, and often notched only on one side, the other side being straighter. Subsequently the thread loses every trace of granule ["globule"] or division, and becomes uniformly transparent, defined, and cylindrical.***Thus the muscular fibre continues when normal until about the period of the sixth month [of the fœtus], except that its substance becomes somewhat more opaque and its cohesion closer. In the sixth month I have recently discerned on these fibres the first traces of transverse striæ, and hence (having now at command one of the best instruments of PLÖSSL) must retract the statement I formerly made, that these transverse striæ are entirely absent in the embryo. These transverse striæ however, during the whole of fœtal life are situated further apart, and discernible only with a clear light and high magnifying power.***From the period at which the muscular threads become transparent and uniform, there accumulate between them masses of round or roundish globules, which are somewhat larger than the blood-corpuscles—viz. 0-000407 Paris line. ***The muscular fibres are formed first, and subsequently their fibrillæ [contained within the fibres].***The younger the embryo is, the coarser are the elementary parts [of muscle].***We have above remarked that from the period at which the muscular fibre becomes uniform and transparent, globules accumulate in large number. Subsequently they diminish, and with the jelly-like mass—which holds them together—enter into the formation of the mucous tissue. This however unites—not the fibrillæ but—the fibres†."

29. More recently, and with reference to the doctrine of "cells," the same physiologist has communicated his views in the following words: "As soon as these [muscular fibres] appear in the fibrous form, there are seen in them round, very pale nuclei, which lie near together. From this it may be inferred, that here the cells arrange themselves likewise longitudinally, but coalesce immediately with one another without being drawn out into fibrillæ. This conjecture is confirmed by the fact that such an embryonic muscular fibre presents itself perfectly pectinate, as a confervafibril with a nucleus in each cell. This pectinate object, however, I have not hitherto so observed, as to have convinced myself of its complete natural conformity. There usually occur two circumstances which either call it forth or make it more distinct: 1. There follow the regular indentations of the muscular fibres, so that between two there always lies a regular nucleus. 2. On the transverse lines, which call forth the pectinate divisions, there lie very minute molecules with opaque contours and a

† Entwicklungsgeschichte des Menschen mit vergleichender Rücksicht der Entwickelung der Säugethiere und Vögel, 1835, pp. 267. 268.

transparent centre, regularly and more or less transversely arranged in lines. The pellucid nucleus is in the interior of the hollow muscular fibre, and often projects in part or wholly when the latter is divided. Subsequently it becomes less and less easily recognizable. Within the muscular fibre there present themselves longitudinal fibrillæ, and soon afterwards transverse striæ. That in the interior of the muscular fibre the cavity remains, seems to be confirmed by my already communicated observation †, that the ends of divided living muscular fibres often become turned inside outwards.‡

30. SCHWANN'S views on the mode of origin of muscle have been published at length in his late work§. They have since appeared in the following condensed form: "According to the observations of VALENTIN, muscles arise out of globules, which apply themselves to one another in rows and then coalesce into a fibre, which represents the primitive muscular *fasciculus*. The fibre so arisen is a hollow cylinder, and in its cavity there lie near together the nuclei of cells (Plate XXX. fig. 18. a.). It is hence probable that the globules of which the fibre is composed were hollow, that is cells, and that the cell-nuclei in this cylinder are the nuclei belonging to those *primary* cells. The earlier process, which I have not observed, must thus have been the following: The (hollow) globules or *primary* cells applied themselves to one another in a row, or coalesced to form a cylinder; and then the partitions—by which the cylinder must have been divided—became absorbed. The nuclei are flat, they lie within the cylinder, not in its axis, but in its wall. This cylinder or *secondary* muscle-cell—rounded off and closed at one extremity—continues to grow like a simple cell; but only in its length, for in breadth it does not increase at all, but rather diminishes. The longitudinal growth, however, does not take place merely at the extremities, but in the whole extent of the cylinder; as is seen from the cell-nuclei—which at first lie near together—separating from one another, and even becoming much elongated themselves. Thus the muscle-fasciculus α (Plate XXX. fig. 18.) becomes converted into β . There now occurs the deposit of another substance upon the inner surface of the cylinder-wall,—that is [upon the inner surface of] the cell-membrane of the secondary muscle-cell,—whereby the wall becomes thickened and the cavity of the cylinder reduced in size (compare the fibre γ with β). That the thickening of the wall is not a thickening of the cell-membrane itself, as in cartilage, follows from the fact that the cell-nuclei do not become pushed towards the cavity of the cylinder, but remain lying at the outer part, in the situation they occupied before the secondary deposit began. This is shown in δ . The secondary deposit continues until the cylinder is entirely filled. The deposited substance becomes converted into very fine fibrillæ, which run longitudinally in the cylinder. These are the primitive muscle-fibres. They thus together form a bundle—the primitive muscular fasciculus—which

† HECKER'S Neue Annalen, II. 71.

‡ VALENTIN, in R. WAGNER'S Lehrbuch der Physiologie, I. pp. 137. 138.

§ Mikroskopische Untersuchungen, &c.

is inclosed by a peculiar structureless wall, the cell-membrane of the secondary muscle-cell†."

31. Such then are the latest published views on the mode of origin of muscle. I have now to record fact, which in some of the main points seem to confirm these views, and to supply further information regarding early periods in the formation of muscular fibre. But should they be found sufficient for these purposes, they will solve a problem of no common interest, and this in a most unexpected manner.

32. The objects in Plate XXX. fig. 17. were found lying together in mucus pressed from the Fallopian tube of a Rabbit killed ten hours *post coitum*. These mixed objects viewed *singly* in the microscope, had the same colour as the corpuscles (red particles) of the Blood,—viz. a yellowish colour. *Accumulations* of such objects—which frequently present themselves—appear blood-red.

33. We have seen a gradual transition of blood-discs into cells for the formation of the chorion,—as in Plate XXIX. figs. 6, 7. If now the objects in Plate XXX. fig. 17. be closely examined and compared with one another, I think it will be difficult to resist the conviction that there is an equally gradual transition from unchanged blood-discs to cells entering into the formation of certain necklace-like fibres in the figure. The question then is, what are these fibres which blood-discs form?

34. In describing the mode of origin of muscle, VALENTIN remarks‡, that globules approach one another and coalesce to form threads, which in many places have a necklace-like appearance, but subsequently lose the traces of division and become cylinders. Could a more appropriate description have been given of the mode of origin of the fibres in my figures 14, 15, 16, 17 §? SCHWANN conjectures|| that the globules now referred to as having been observed by VALENTIN, are cells; that these coalesce to form a secondary cell, that is, the cylinder; and that the nuclei contained in the cylinder are the nuclei of the primary cells. He found the nuclei flat, and not in the axis of the cylinder but in its wall. My observations realise these conjectures of SCHWANN, and the figures just referred to attest the accuracy of his observations. I would here compare my fig. 15. with δ of fig. 18., borrowed for the sake of comparison from SCHWANN, and exhibiting a later stage; and if several objects in my

† SCHWANN, in R. WAGNER's *Lehrbuch der Physiologie*, i. pp. 140, 141. He adds: "A process entirely analogous to that which forms muscle is in operation, according to MEYER, in the cells of the inner bark of trees. Here also there arise simple cells, which apply themselves to one another in a row, and through coalescence at the points of contact of the cell-membranes, and absorption of these coalesced partitions, become converted into a *secondary* cell, the wall of which thickens from a secondary deposit. The only question is, whether the substance which produces this thickening consists of longitudinal fibres" [*fibrille*], p. 141.

‡ See the quotations from this author, pars. 28. 29.

§ The objects in all these figures were pressed from the Fallopian tube, which it will be recollected becomes muscular at the period to which these observations have reference. Figs. 14 and 15. represent a minute portion only (merely the extremity), of a very considerable mass of fibres.

|| See the quotations from this author, par. 30.

fig. 17. be compared with γ of fig. 18., taken from that author, a further correspondence will be observed. But it is not needful to refer to the observations of others, since the objects figured by myself were *obviously muscular fibres* (the future fasciculi) in the earliest stages of formation. There is therefore, it appears, a direct transition of blood-discs into the elementary parts of muscle.

35. My observations have not extended farther than the condition $\gamma\gamma$ of fig. 17.—for they were almost entirely incidental;—so that I am unable to state the mode of origin of the fibrillæ within the cylinder. But certain facts communicated in my Third Series of Researches in Embryology, may perhaps be applicable here.

36. It was there shown that a nucleus, after passing to the centre of a cell, resolves itself into the foundations of new cells. I would suggest that the nucleus may *thus* be the source of that "secondary deposit" described by VALENTIN and SCHWANN as thickening the membrane of the cylinder; and am the more disposed to think this possible, from the observations of SCHWANN on the frequent metamorphosis of cells into fibres. The existence of the longitudinal fibrillæ might perhaps be thus explained, for SCHWANN remarks, that these fibrillæ are formed out of the "secondary deposits."—This suggestion corresponds to one offered in my last memoir on the possible mode of origin of spiral fibres and other secondary deposits in vegetable cells.

37. It is not needful, however, that the central portion of a nucleus should leave the membrane of its cell, before the resolution of the free portion of such nucleus; of which the germinal spot in its last stages affords a remarkable example†. I regard the pellucid objects in the cells Plate XXX. figs. 15. 17‡, as occupying the place of the pellucid centres of the blood-corpuscles.

38. In the cells fig. 16. no such pellucid objects were observed at the surface. But the cells presented a lighter central space, which I believe to have corresponded to the pellucid objects in question,—these having passed to that situation. And if the pellucid objects here seen are the seat of changes analogous to those presented by the mysterious centres of nuclei elsewhere§, it is not difficult to conceive the mode of origin of the "secondary deposits" above referred to||. The object $\beta\beta$ in fig. 17. presented a state apparently rather more advanced than those in fig. 16. The cells, however, had not coalesced. In $\gamma\gamma$ of fig. 17. the coalescence had more or less completely taken place; and it is deserving of notice, that what in $\beta\beta$ appeared the separate pellucid objects in question, had in $\gamma\gamma$ also coalesced, or seemed about to coalesce, to constitute the medullary portion of the cylinder. From the state of the fibre $\gamma\gamma$, it appears also that secondary deposits are in progress before the cylinder is fully formed.

† "Third Series," I. c., pars. 327, 328.

‡ And also those in Plate XXIX. fig. 7, &c.

§ "Third Series," I. c., pars. 375 to 395.

|| That the pellucid object in the altered blood-disc really undergoes these changes, is to be inferred from Plate XXX. fig. 20. (par. 44.)

39. The purpose answered by the pellucid objects retaining in some instances a peripheral locality (fig. 18. δ . from SCHWANN), is no doubt an important one; but on this subject I do not hazard a conjecture.

40. The blood-corpuscles when passing into cells for the formation of muscular fibre, are darker in colour than those destined to form the chorion. There seems to occur in them an increase of red colouring matter (par. 43.).

41. The masses of globules seen by VALENTIN (par. 28.) to accumulate between the muscular threads,—globules which were “round or roundish” and “somewhat larger than the blood-corpuscles,”—I would suggest may really have been blood-corpuscles, which had assumed a globular form, and increased in size in the manner above described. VALENTIN, however, states that the globules in question entered into the formation of the “uniting mucous tissue†.”

42. In connexion with the fact now recorded, that muscular fibre is formed of corpuscles of the blood, an observation may be referred to which has been mentioned by several authors‡; namely, that of a disposition to run into combinations, and form objects compared by HEWSON to rolls of coin. I find it very usual for this appearance to arise in blood obtained by a puncture (as of the finger), and to which no addition has been made.—R. WAGNER mentions that in blood taken from the heart of some of the Invertebrata—*Unio* and *Anodonta*—when the coagulating fibrin makes its appearance, blood-corpuscles are seen—often grouped necklace-like—around it.

43. Others have supposed muscular fibre to be formed by the blood-discs; but I am not aware of any facts having been observed which warranted the supposition. It is remarkable that a conjecture on this subject in one of the papers of Sir EVERARD HOME§ should have approached so near the truth. His conjecture was, “That the globules may be the part of the blood, out of which the muscular fibres are principally formed||.” Between Sir E. HOME’s observations and my own, however, it will be perceived that there are material differences. For instance, he remarks, “When the globules of the human blood lose the colouring matter, they continue floating in the serum, and are seen to have an attraction towards one another so as to coalesce, uniting themselves together¶.” In the altered corpuscles—that is, cells—which I saw uniting to form muscular fibre, the colour—so far from having disappeared—seemed (as already mentioned) to have become more intense (par. 40.).

State of the Blood-corpuscles during Vital Turgescence of the Vessels.

44. The appearance presented by the capillaries in highly vascular conditions of the internal generative organs, is remarkable. An idea of it may be obtained from Plate XXX. fig. 20, taken from a portion of the inner surface of the infundibulum of the

† *Entwicklungsgeschichte*, &c., S. 269.

‡ HEWSON (*l. c.*, p. 28.), HODGKIN and LISTER (*l. c.*, p. 436.), R. WAGNER (*l. c.*, p. 6.).

§ The Croonian Lecture, *Philosophical Transactions*, 1818, p. 172.

|| *Ibid.* pp. 174, 175.

¶ *Ibid.* p. 174.

Fallopian tube in a Rabbit killed 5½ hours *post coitum*. The vessels were filled with blood-corpuscles apparently to the exclusion of surrounding fluid. The corpuscles, in depth of colour, cell-like form, and general appearance, resembled those above described as entering into the formation of muscular fibre; but in most of them the usual place of the contained pellucid object was occupied by a substance which was obscure and dark, though presenting in some of the corpuscles a pellucid central point. This, however—from observations on the varying state of the interior of nuclei, and the continual origin there of fresh objects, recorded in my "Third Series"—so far from constituting a difference, seems to furnish a confirmation of my views as to the nature of the pellucid objects in question (par. 38.).—The largest vessel in this figure measured in external diameter $\frac{1}{300}$ ". But I have seen a vessel so filled, of many times this size.

45. The description now given of fig. 20. is applicable to the states of capillaries constantly observed at the period in question. The figure shows, that the corpuscles, having assumed a more or less globular or elliptic form, so completely fill their vessels as to be compressed into polyhedral shapes, and even to produce inequalities in the calibre of their vessels. When examined immediately after death, the contents of such vessels have in some instances exhibited here and there a slight degree of motion.

46. The vessels constituting a network under the epithelium-cells which carry cilia, and present the frill-like appearance in the outline fig. 19†, are filled with corpuscles in the above altered states‡. In other parts (fig. 21.) vessels are found so filled, which do not exhibit the same immediate connexion with the cilia-bearing cells.

47. I have seen both in the Fallopian tube and on its fimbriated extremity, a curious network (fig. 22.), apparently formed by the coalescence of blood-corpuscles, which, like those entering into the formation of the chorion, seemed for this purpose to have sent out processes or arms. The finest ramifications in arborescent states of the capillaries like that in fig. 21, have sometimes appeared to pass into a network of this kind§.

48. The above-described condition of the blood-corpuscles during vital turgescence of the vessels, I think deserving of consideration, in connexion with many of the phenomena attending local accumulations of blood, both in health and in disease; and more especially with reference to increased pulsation, the exudation of colourless fluid, and the heat and redness of inflamed parts.

49. Incipient epithelium-cells often present appearances which almost suggest the idea that these too are changed corpuscles of the blood. Compare in Plate XXIX. figs. 10, 11 with fig. 12. It is at least difficult to draw a line by which the two can

† See the explanation of the Plates.

‡ It is a part of fig. 19. which is represented on a larger scale in fig. 20.

§ On one occasion I observed a vermicular motion in a minute portion of such a network.

be distinguished, either in colour, form, or general appearance. (The epithelium-cells in question are frequently observed to lie in the same direction, their long axes being parallel.)

50. But if the great mass of the soft parts, muscle, is formed of corpuscles of the blood, how many tissues are there which they may not form?†

51. We are indebted to SCHWANN for the very important discovery, that "for all the elementary parts of organisms there is a common principle of development;" the elementary parts of tissues having, as he has shown, a like origin in cells, however different the functions of those tissues. The facts made known in the present memoir, if established by future observation, will not only afford proofs of the justness of the views of SCHWANN, but they will farther show that objects having all the same colour, form, and general appearance, namely, the corpuscles of the blood, enter immediately into the formation of tissues which physiologically are extremely different. We have seen some of these corpuscles to arrange themselves into muscular fibre, and others to become metamorphosed into constituent parts of the chorion. It is not, however, more difficult to conceive objects so much alike undergoing transformations for purposes so different, than it is to admit a fact made known by two of my preceding memoirs‡; namely, that the nucleus of a cell having a central situation in the group which constitutes the germ, is developed into the whole embryo, while the nuclei of cells occupying less central situations in the group, form no more than a minute portion of a membrane§. It is known that in the bee-hive, a grub is taken for a special purpose, from among those born as workers, which it perfectly resembles until nourished with peculiar food, when its development takes a different course from that of every other individual in the hive.

† "The nerves," says SCHWANN, "appear to arise in the same manner as the muscles; namely, through coalescence of primary cells in contact with one another and in a line, by which there is formed a secondary cell. But the primary nerve-cells have not been with certainty observed, because—so long as they are primary cells—they are not to be distinguished from the neutral cells, out of which arises the whole organ."**The fibres [secondary cells] are pale, granulated, and***hollow. There now takes place, as in muscles, a secondary deposit upon the inner surface of the fibre-wall, that is, upon the inner surface of the membrane of the secondary nerve-cell.***On the appearance of this deposit the cell-nuclei are usually absorbed; yet single ones continue, and then lie externally between the [deposited] substance and the [secondary] cell-membrane.***as in muscles. The remaining cavity of the secondary cell appears to be occupied by a tolerably firm substance, the band discovered by REMAK." (SCHWANN in R. WAGNER's *Lehrbuch der Physiologie*, I. pp. 141, 142.) Should it be found that nerves too are formed of blood-corpuscles, this band of REMAK may perhaps be constituted by coalesced objects similar to those apparently uniting to form the central substance in the muscle-cylinder (par. 38.), and which appear to be the essential part of altered corpuscles of the blood.—"The external appearance of tendons in the embryo," says VALENTIN, "is reddish, and not unlike the pale muscle-structures." (*Entwickelungs-geschichte*, p. 270.)

‡ *Researches in Embryology*, Second and Third Series, I. c.

§ Which I provisionally called the amnion.

52. EXPLANATION OF THE PLATES.

PLATE XXIX.

Fig. 1. Blood-corpuscles in fluid collected on the fimbriated portion of the Fallopian tube in a Rabbit killed eleven hours *post coitum*. α . Usual state, or but little altered; β . incipient division into globules; γ . more advanced stage in this division (paragraphs 2. 3. 4.).

Fig. 2. Blood-corpuscles in fluid collected on the ovary in a Rabbit killed seven hours *post coitum*. α . Usual state, or but little changed. The corpuscles in this figure which are not distinguished by a letter, present various stages in the division into globules, incipient in β of the preceding figure. Among the corpuscles are some in which the pellucid central portion is bounded by a dark line. Several are represented as viewed more or less laterally. In δ , the division has proceeded so far as to present the appearance of distinct though still adherent globules (par. 2 to 5. 8.). ϵ . Objects found with the foregoing (see par. 10.).

Fig. 3. Blood-corpuscles in fluid collected on the fimbriated portion of the Fallopian tube in a Rabbit killed five hours *post coitum*. These corpuscles were in motion. Those at α resembled several in fig. 2. β Appeared to be horizontally revolving on its axis. The corpuscles on the right side of β seemed to consist of a central and a peripheral portion, more or less corresponding in appearance to those at α ; but in most instances the peripheral portion was less distinctly separated into globules, and in all of them the form was undergoing rapid and incessant change. γ . The central pellucid fluid had separated into three portions, and the motions of the entire object were such as to suggest the idea of its being about to undergo a like separation. The motions of these corpuscles were observed two hours and a half after death (par. 12 to 19.).

Fig. 4. Blood-corpuscles in fluid collected on the fimbriated portion of the Fallopian tube in a Rabbit killed thirteen hours *post coitum*. These, when first observed, were rapidly and incessantly changing their form. When their motions ceased they retained the forms exhibited in the figure. Their pellucid centres were scarcely, if at all, seen while the motions continued. Sometimes they appeared almost to separate into two portions, and then recover their previous form. The motion ceased gradually, gentle undulations having been the last change observed (par. 12 to 19.).

Fig 5. Several of the appearances presented by a blood-corpuscle observed changing its form as above described. The pellucid fluid, sometimes central (α),

seemed at other times on one side (β), and at others as though divided into several parts (γ). Taken from fluid collected on the fimbriated portion of the Fallopian tube, in a Rabbit killed $5\frac{1}{2}$ hours *post coitum* (par. 12 to 17.).

Fig. 6. Blood-corpuses from the Fallopian tube of a Rabbit killed twelve hours *post coitum*. Many of them (α) flat, and in a condition little changed; others (β) become orange-shaped cells, a portion of their interior pellucid. In some (γ) the pellucid portion was seen to be, not central but, on one side. Certain of them (δ) had become elliptical. Some (ϵ) presented very minute adherent granules or globules (pars. 20. 21. 33.).

Fig. 7. Blood-corpuses—now true cells—from the Fallopian tube of a Rabbit killed fourteen hours *post coitum*. Some of them (δ) resembled δ in fig. 6. Others had considerably enlarged, and sent out processes or arms. Such as these enter into the formation of the chorion. When viewed singly, the objects in this figure—with the exception of the pellucid portion which each presents—appeared yellowish; an accumulation of such objects is blood-red (pars. 21. 24. 25. 33.).

Fig. 8. Outline of part of an ovum of twelve hours, and measuring $\frac{1}{14}''$, from the Fallopian tube. The cells of the tunica granulosa (g^1)—also for the most part in outline—had become club-shaped, and were in contact with the membrane f by their pointed extremities alone. The object of this figure is to show some of the very earliest traces of the formation of the chorion. Blood-corpuses ($cho.$), having found their way between the cells g^1 , apply themselves to the membrane f , and undergo the changes elsewhere described. Three of these corpuses had passed into the state of cells, the contained pellucid object being at the surface; and two of these cells had begun to send out processes or arms (par. 25.). e . Proper membrane of the substance surrounding the germinal vesicle. Between this membrane and the membrane f there was a space, filled with transparent fluid.

Fig. 9. Blood-corpuses in fluid collected in the infundibulum of the Fallopian tube of a Rabbit killed in the state of heat.

Fig. 10. Altered and now spheroidal blood-corpuses in fluid collected in the infundibulum of the Fallopian tube, in a Rabbit killed four hours *post coitum* (par. 49.).

Fig. 11. Altered blood-corpuses in fluid collected on the fimbriated portion of the Fallopian tube, in a Rabbit killed in the state of heat (par. 49.).

Fig. 12. Epithelium-cells, found with the blood-corpuses in the preceding figure, and having very much the appearance of being formed out of such corpuses. Some of them were beginning to send out a process, and they were all lying in nearly the same direction (par. 49.).

- Fig. 13. Another form of epithelium-cells—formed of blood-corpuscles (?)—found with those in the preceding figure. Colour yellowish, except the contained pellucid objects. Their long axes parallel.

PLATE XXX.

- Fig. 14. Blood-corpuscles—now cells—arranging themselves to form muscle. Found with an ovum of ten hours, taken from the Fallopian tube (par. 34.).
- Fig. 15. A portion of the same, more highly magnified. The pellucid objects contained in the blood-corpuscles (now cells) in many instances were seen to be situated—not in the centre but—on one side. When viewed singly, these objects appeared yellowish; in a mass, blood-red (pars. 34. 37.).
- Fig. 16. Blood-corpuscles—now cells—arranging themselves to form muscle. Some of them remarkably elongated (pars. 34. 38.). Found in the Fallopian tube of a Rabbit killed eleven hours *post coitum*.
- Fig. 17. Blood-corpuscles (α, γ, δ), and portions of muscle ($\beta\beta, \gamma\gamma$) formed of blood-corpuscles, found with the objects figs. 14 and 15. This figure presents several transition states between the unchanged blood-disc α , and the necklace-like arrangement of cells $\beta\beta$. In the latter, the contained pellucid object had a central situation, but the cells had scarcely coalesced. $\gamma\gamma$ Presents a more advanced state. Here the cells had more or less coalesced into a cylinder, and the contained pellucid objects together formed, or seemed about to form, the medullary portion of the cylinder. In this figure are also objects resembling fig. 15. (pars. 32 to 35. 37. 38.).
- Fig. 18. From SCHWANN (in R. WAGNER's "Icones Physiologicæ," Tab. XII. fig. 4.). α to δ , "Different stages in the development of muscle" (pars. 30. 34. 39.).
- Fig. 19. Outline of capillaries as seen in a portion of the infundibulum of the Fallopian tube, taken from its inner surface, in a Rabbit killed $5\frac{1}{2}$ hours *post coitum*. These vessels were filled with blood-corpuscles in the state represented in fig. 20. At the lower part of this figure (fig. 19.) are epithelium-cells carrying cilia. These epithelium-cells are arranged parallel to one another, and perpendicular to the general direction of the capillary vessels. The small extremity of the epithelium-cells is directed towards the capillaries. Whence their frill-like appearance (in the figure), and the great extent of their ciliary surface. External diameter of the largest vessel $\frac{1}{300}$ ". 100 *diam.* (par. 46.)
- Fig. 20. A portion of the capillary vessels in the preceding figure, more highly magnified (300 *diameters*), to show the appearance of the blood-corpuscles with which they were filled. The blood-corpuscles presented in their

interior an object, which in most instances was more opaque (redder) than the remainder of the corpuscle; but in some of the corpuscles the corresponding situation was occupied by a pellucid object (pars. 44. 45.).

Fig. 21. Outline of capillaries from the inner surface of the infundibulum of the same Rabbit, and filled with blood-corpuscles in the same condition as those in fig. 20; but not related to ciliated epithelium-cells in the manner exhibited in fig. 19. The external diameter of the largest vessel measured $\frac{1}{100}$ " diam. (pars. 46. 47.)

Fig. 22. Network formed apparently of altered blood-corpuscles, the arms of which (see Plate XXIX. fig. 7.) have coalesced. Found with the objects in Plate XXIX. figs. 11. 12. 13. (par. 47.).

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1840.

A.

Actinograph, description of an, 46.

AIRY (GEORGE BIDDELL, Esq.). On the theoretical explanation of an apparent new polarity of light, 225.

Ammoniac resin, 350.

Archil and *litmus*, contributions to the chemical history of, 273. Section I. Chemical examination of the *Roccella Tinctoria* (archil-weed), 275; I. Of erythryline, 277; II. Of erythrine, 279; III. Of erythrine-bitter.—Amarythrine, 282; IV. Of telerythrine, 283. Section II. Chemical examination of archil (orseille) of commerce, 285; I. Of azoerythrine, 287; II. Of orceine, 289; III. Of erythroleic acid, 295. Section III. Of litmus, 298; I. Of erythrolein, 299; II. Of erythrolitmine, 301; III. Of azolitmine, 304; IV. Of Spaniolitmine, 307. Section IV. Of the decolorization of the bodies which exist in *archil* and *litmus*, 311; action of chlorine on azolitmine, 321; action of chlorine on erythrolitmine, 322.

Assafetida, resin of, 354.

B.

BAKERIAN LECTURE, 225.

BARRY (MARTIN, M.D.). Researches in Embryology. Third series: A contribution to the physiology of cells, 529.

On the corpuscles of the blood, 595.

Bdellium, resin of, 368.

BELL (SIR CHARLES). On the nervous system, 245.

Benzoin, resin of, 369; action of caustic lime on, 372; action of caustic potash on, 375; action of oxide of lead on, 378; on the rational constitution of the, 380; general results in regard to the, 383.

Berengela resin, 346.

Blood, on the corpuscles of the, 595; progressive division of the blood-disc into globules, *ibid.*; rapid and incessant changes in the form of altered blood-corpuscles, 598; the chorion formed of cells derived from corpuscles of the blood, 600; muscular fibre formed of cells derived from corpuscles of the blood, 601; state of the blood-corpuscles during vital turgescence of the vessels, 606; explanation of the plates, 609.

BOWMAN (WILLIAM, Esq.). On the minute structure and movements of voluntary muscle, 457.

C.

Calorific rays in the solar spectrum, on the distribution of the, 51.

Calorific spectrum, account of a process for rendering it visible by its effect on paper properly prepared, and of some further results obtained respecting the distribution of heat therein, 52.

Cells, contribution to the physiology of, 529; the doctrine of, 530; parent-cell, the germinal vesicle, 536; twin cells, 537; reproduction of succeeding cells, 539; the rudimental embryo is the nucleus of a cell, 541; the chorion formed of cells arising in the oviduct, 545; application of facts to the physiology of cells, 546; existing views regarding cells, 563; chorion formed of cells derived from corpuscles of the blood, 600; muscular fibre formed of cells derived from corpuscles of the blood, 601.

Chemical action (combined) of rays of different degrees of refrangibility, 23; traced much beyond the extreme red rays, 28, 31.

——, the source of power in the voltaic pile, 61, 93; sufficiency of to produce voltaic currents, 117.

—— of the rays of the solar spectrum on preparations of silver and other substances, both metallic and non-metallic, 1.

Chemical theory of voltaic electricity, 64; comparison of with contact theory, 77; adequate to explain the phenomena, 61, 93.

Chlorine, action of, on azolitmine, 321; on erythrolitmine, 322.

Chorion, formed of cells arising in the oviduct, 545; diameter of liable to much greater changes than that of the zona pellucida, 566; formed of cells derived from corpuscles of the blood, 600.

Clock, description of an escapement for an astronomical, 335.

Contact theory of voltaic electricity, 62; comparison of with chemical theory, 77; inadequate to explain the phenomena, 61, 93; improbable nature of the assumed contact force, 124.

D.

DANIELL (J. FREDERIC, Esq.). Second letter on the electrolysis of secondary compounds, 209.

DUNLOP (JAMES, Esq.). Table of observations by, of the dip and intensity, made at sea in a voyage from England to Australia, 146.

E.

Electricity, experimental researches in. Sixteenth series, 61. § 24. On the source of power in the voltaic pile, various views of contact and chemical excitement, 62; theory of contact electromotive force, 64. i. Exciting electrolytes, &c. being conductors of thermo and feeble currents, 66. ii. Inactive conducting circles containing a fluid or electrolyte, 68; chemical and contact theories compared, 77. iii. Active circles excited by solution of sulphuret of potassium, &c. 82.

——. Seventeenth series, 93. § 24. On the source of power in the voltaic pile (continued). iv. The exciting chemical force affected by temperature, 93; cases of one metal and one electrolyte; one junction being heated, 99; cases of two metals and one electrolyte; one junction being heated, 102. v. The exciting chemical force affected by dilution, 104. vi. Differences in the order of the metallic elements of voltaic circles, 112. vii. Active voltaic circles and batteries without metallic contact, 114. viii. Considerations of the sufficiency of chemical action, 117. ix. Thermo-electric evidence, 122. x. Improbable nature of the assumed contact force, 124. *Note* 127.

Electricity, voltaic, contact theory of, 62; chemical theory of, 64; chemical and contact theories of, compared, 77.

Electrolysis of secondary compounds, on the, 209.

Elemi resin, 366.

Embryo, the rudimental, is the nucleus of a cell, 541.

Embryology, researches in. Third series: A contribution to the physiology of cells, 529; the

doctrine of cells, 530; changes in the ovarian ovum preparatory to fecundation, *ibid.*; changes in the ovum immediately after fecundation and before it leaves the ovary, 534; changes in the ovum after its discharge from the ovary. Addition of the chorion, 536; recapitulation, 554; appendix, 558; table of measurements, 567; explanation of the plates, 569; additional observations, 590.

Escapement, description of an, for an astronomical clock, invented by the late Captain Henry Kater, F.R.S., drawn up from his own memorandums, 335.

Euphorbium resin, 364.

F.

Fallopian tube, ova found in the, of the Rabbit, 565.

FARADAY (MICHAEL, D.C.L.). Experimental Researches in Electricity. Sixteenth series: On the source of power in the voltaic pile, 61.

Seventeenth series: On the source of power in the voltaic pile (continued), 93; *Note*, 127.

Fasciculus (Primitive) of voluntary muscle, 458; table of diameters of, 460; transverse striæ in, 461; fibrille of marked, 463; not tubular, but consists of a true bundle of fibrille, 466; sarcolemma or tunic of, 474; corpuscles of, 482; of the extremities of, and union to other structures, 485.

Fecundation, changes in the ovarian ovum preparatory to, 530; point of, 532; changes in the ovum immediately after, 534.

G.

GASSIOT (JOHN P., Esq.). An account of experiments made with the view of ascertaining the possibility of obtaining a spark *before* the circuit of the voltaic battery is completed, 183.

Geology (Physical), Researches in, second series, 193; on precession and nutation, assuming the interior of the earth to be fluid and heterogeneous, 193.

Germ, the, or foundation of the new being; its place of origin and form, 536; comparison of the germs of animals and plants, 553.

Germinal vesicle, and spot, changes in, preparatory to fecundation, 531; immediately after fecundation, 534; not a nucleus, but a parent-cell, 536; statements and conjectures of physiologists on the nature, office, and destination of the germinal vesicle, 558.

H.

HERSCHEL (SIR JOHN F. W., Bart.). On the chemical action of the rays of the solar spectrum on preparations of silver and other substances both metallic and non-metallic, and on some photographic processes, 1. I. Of fixing photographs, 4. II. Of taking photographic copies and transfers, 7. III. Of the preparation of photographic paper, 8. IV. Chemical analysis of the solar spectrum, 15; extension of the visible prismatic spectrum,—a new prismatic colour, 19; chemical properties of the red end of the spectrum, 22; combined action of rays of different degrees of refrangibility, 23; chemical action traced much beyond the extreme red rays;—exercise of a blackening or deoxidating power by the red rays themselves, under certain circumstances, 28; possible indication of absorptive action in the sun's atmosphere, 29; existence of a blackening or deoxidating power in rays beyond the extreme red, 31; effect of the spectrum on certain vegetable colours, 33. V. Of the whitening power of the several rays of the spectrum under the influence of hydriodic salts, on papers variously pre-

pared and previously darkened by the action of solar light, 35. VI. Of the analysis of the chemical rays of the spectrum by absorbent media, 37. VII. Of the exalting and depressing power exercised by certain media, under peculiar circumstances of exposure to solar light, on the intensity of its chemical action, 43. VIII. Description of an actinograph, or self-registering photometer for meteorological purposes, 46. *Note I.* On the distribution of the calorific rays in the solar spectrum, 51. *Note II.* On a definite limit of photographic action of the blue rays under the influence of an iodic salt, 52. *Note III.* Account of a process for rendering visible the calorific spectrum by its effect on paper properly prepared, and of some further results obtained respecting the distribution of heat therein, 52.

HODGKINSON (EATON, Esq.). Experimental researches on the strength of pillars of cast iron and other materials, 385.

HOPKINS (WILLIAM, Esq.). Researches in physical geology. Second series, 193.

HUNT (Mr. ROBERT). On the influence of iodine in rendering several argentine compounds, spread on paper, sensitive to light, and on a new method of producing, with greater distinctness, the photographic image, 325.

Hydriodic salts, of the whitening power of the several rays of the spectrum under the influence of the, on papers variously prepared and previously darkened by the action of solar light, 35.

I.

Iodine, on the influence of, in rendering several argentine compounds, spread on paper, sensitive to light, and on a new method of producing, with greater distinctness, the photographic image, 325.

Iron (cast). Experimental researches on the strength of pillars of, 385; power of to resist long-continued pressure, 417; tensile strength of, 418; compressive strength of, 419; transverse strength of, 420; relative strength of long pillars of cast iron, wrought iron, steel, and timber, 430; tables of the results of experiments on the strength of cylindrical, rectangular and other forms of pillars, 431, 449.

Iron (wrought). Strength of pillars of, as dependent on their dimensions, 423; table of the results of experiments on the strength of pillars, 451.

J.

Jalap, resin of, 342.

JOHNSTON (JAMES F. W., Esq.). On the constitution of the resins, Part IV., 341.

— On the constitution of the resins, Part V., 361.

K.

KANE (ROBERT, M.D.). Contributions to the chemical history of archil and litmus, 273.

KATER (EDWARD, Esq.). Description of an escapement for an astronomical clock, invented by the late Captain HENRY KATER, drawn up from his own memorandums, 355.

KATER (Captain HENRY). Description of an escapement for an astronomical clock invented by the late, 355.

L.

Labdanum, resin of, 344.

Light. A supplement to a paper entitled "Remarks on the Theory of the Dispersion of Light, as connected with Polarization," 157.

Light, on the influence of iodine in rendering argentine compounds sensitive to, 325.

—, on the theoretical explanation of an apparent new polarity in, 225.

Litmus, archil and, contributions to the chemical history of, 273. Section III. Of litmus, 298;

I. Of erythrolein, 299; II. Of erythrolitmine, 301; III. Of azolitmine, 304; IV. Of spaniolit-

mine, 307. Section IV. Of the decolorization of the bodies which exist in archil and *litmus*,

311; action of chlorine on azolitmine, 321; action of chlorine on erythrolitmine, 322.

M.

MACLEAR (THOMAS, Esq.). Further particulars of the fall of the Cold Bokkeveld meteorolite, 177.

Magnetic dip and intensity, table of observations of the, made at sea between Falmouth and the Falkland Islands, 142.

—, Table of observations of the, made at sea in a voyage from England to Australia, 146, 147, 150.

Magnetic inclination and intensity, lines of, in the Atlantic Ocean, 129; *intensity*, between the Cape of Good Hope and Australia, 140.

Magnetism, terrestrial, contributions to, 129; § i. Lines of inclination and intensity in the Atlantic Ocean, 129; § ii. Lines of intensity between the Cape of Good Hope and Australia, 140.

Media, absorbent, of the analysis of the chemical rays of the spectrum by, 37; of the exalting and depressing power exercised by certain media, under peculiar circumstances of exposure to solar light, on the intensity of its chemical action, 43.

Meteorolite (the Cold Bokkeveld). Further particulars of the fall of, 177.

Muscle (*voluntary*). On the minute structure and movements of, 457; primitive fasciculus, 458; table of diameter of primitive fasciculi, 460; of the transverse strie, 461; of the sarcolemma, or tunic of the primitive fasciculus, 474; of the corpuscles of the primitive fasciculus, 482; of the extremities of the primitive fasciculi, and their union to other structures, 485; on the mechanism of the movement of voluntary muscle, 487; recapitulation of the chief results, 493; postscript, 494; explanation of the plates, 495.

Muscular fibre formed of cells derived from corpuscles of the blood, 601.

N.

Nervous system, on the, 245; the spinal nerves, *ibid.*; the respiratory system of nerves, 249; of the supply of blood to the nerves of the respiratory system, 253.

Nutation, precession and, phenomena of, assuming the interior of the earth to be fluid and heterogeneous, 193.

O.

Opoponax, resin of, 352.

Ovum, changes in the ovarian, preparatory to fecundation, 530; changes in the, immediately after fecundation and before it leaves the ovary, 534; after its discharge from the ovary, 536; no fixed relation between the degree of development of ova and their size, locality, or age, 544; ova found in the Fallopian tube and uterus of the Rabbit, 564.

OXMANTOWN (Right Honourable Lord). An account of experiments on the reflecting telescope, 503.

P.

PALGRAVE (Sir FRANCIS, K.H.). An account of the shooting stars of 1095 and 1243, 175.

- Photographic action*, on a definite limit of, of the blue rays under the influence of an iodic salt, 52.
 ——— *image*. On a new method of producing it with greater distinctness, 325.
 ——— *papers*, 327; method of using, 332.
 ——— *processes*, on some, 1. I. Of fixing photographs, 4; II. Of taking photographic copies and transfers, 7; III. Of the preparation of photographic paper, 8.
Photometer, self-registering, for meteorological purposes, 46.
Pillars of cast iron and other materials, experimental researches on the strength of, 385; comparative strength of cylindrical pillars of cast iron, with rounded and with flat ends, 387; strength of long pillars of cast iron, 390; of pillars with one end rounded and the other flat, 393; of pillars enlarged in the middle, 395; of long pillars as dependent upon their dimensions, *ibid.*; — upon the diameter, *ibid.*; — on the length, 398; computations of the strength of long pillars by means of the numerical results from experiments, 400; short pillars, diminution in their strength from crushing, 403; mode of estimating the strength in short pillars, 404; relative strength of similar pillars, 400; strength of hollow cylindrical pillars of cast iron, 408; computed strength, 414; strength of short hollow pillars, 416; power of cast iron to resist long-continued pressure, 417; tensile strength of cast iron, 418; compressive strength of cast iron, 419; transverse strength of cast iron, 420; strength of pillars of wrought iron, of steel, and of timber, *ibid.*; strength of pillars of wrought iron as dependent on their dimensions, 423; — of timber, 424; — crushing strength of timber, 429; relative strength of long pillars of cast iron, wrought iron, steel, and timber, 430; Tables: I. Results of experiments on the resistance of solid uniform cylinders of cast iron to a crushing force, the ends rounded, 431; II. Ends of the cylinders turned flat, 434; III. Rectangular or square uniform pillars, 437; IV. Solid uniform cylindrical pillars with discs upon their ends, 438; V. Uniform pillars, with one end rounded and one flat; with both ends rounded; with both flat, 439; VI. Pillars enlarged in the middle, ends rounded, 440; VII. Pillars enlarged in the middle, with discs on the ends, 441; VIII. Hollow cylinders rounded at the ends, 442; IX. Hollow cylinders flat at the ends, 445; X. Short hollow cylinders, 448; XI. Pillars of various forms and different modes of placing, 449; XII. Pillars of wrought iron and steel, 451; XIII. Pillars of Dantzic oak and red deal, 453.
 POWELL (the Rev. BADEN). A supplement to a paper entitled "Remarks on the Theory of the Dispersion of Light as connected with Polarization," 157.
Precession and nutation, phenomena of, assuming the interior of the earth to be fluid and heterogeneous, 193.
Prismatic colour, a new, 19.
 ——— *spectrum*, extension of the visible, 19.

R.

- Rabbit*, ova found in the Fallopian tube and uterus of the, 565; table of measurements of ova, 567.
Rays of the solar spectrum, on the chemical action of the, on preparations of silver and other substances, both metallic and non-metallic, 1; combined chemical action of rays of different degrees of refrangibility, 23; of the whitening process of the several, under the influence of the hydriodic salts, on papers variously prepared and previously darkened by the action of solar light, 35; analysis of the chemical, by absorbent media, 37.
Red rays, chemical action traced much beyond the extreme, 28, 31; exercise of a deoxidating power by the, 28.
Resins, on the constitution of the. Part IV., 341; IX. Resin of scammony, *ibid.*; X. Resin

of jalap, 342; XI. Resin of labdanum, 344; XII. Berengela resin, 346; XIII. Resin of retin-asphalt, 348; XIV. Ammoniac resin, 350; XV. Resin of opoponax, 352; XVI. Resin of assafetida, 354; general remarks, 358.

Resins, on the constitution of the. Part V., 361; XVII. Resin of sagapenum, *ibid*; XVIII. Resin of galbanum, 362; XIX. Euphorbium resin, 364; XX. Elemi resin, 366; XXI. Resin of bdellium, 368; XXII. Resin of benzoin, 369; action of caustic lime on resin of benzoin, 372; action of caustic potash on resin of benzoin, 375; action of oxide of lead on resin of benzoin, 378; on the rational constitution of the resin of benzoin, 380; general results in regard to the resin of benzoin, 383.

Retin-asphalt, resin of, 348.

S.

SABINE (Major EDWARD, R.A.). Contributions to terrestrial magnetism, 129. § 1. Lines of inclination and intensity in the Atlantic, *ibid*. § 2. Lines of intensity between the Cape of Good Hope and Australia, 140.

Sagapenum, resin of, 361.

Sarcolemma, or tunic of the primitive fasciculus of voluntary muscle, 474.

Scammony, resin of, 341.

Shooting stars. An account of those of 1095 and 1243, 175.

Solar spectrum, on the chemical action of the rays of the, on preparations of silver and other substances, both metallic and non-metallic, 1; chemical analysis of the, 15; phenomena observed on presenting particular preparations to the action of the, 27; effect of, on certain vegetable colours, 33; of the whitening power of the several rays under the influence of hydriodic salts, on papers variously prepared and previously darkened by the action of solar light, 35; analysis of the chemical rays, by absorbent media, 37; on the distribution of the calorific rays in the, 51.

Speculum of a reflecting telescope. Proportion of copper and tin in metal for, 505; method of forming a large speculum of several castings, *ibid*; process of casting, 509; processes of grinding and polishing, 514.

Spectrum, prismatic, extension of the visible, 19; calorific, account of a process for rendering it visible, 52.

Steel, strength of pillars of, 421, 430, 452.

Strength of pillars. See pillars, iron, steel, timber.

SULIVAN (Lieut. B. J., R.N.). Table of observations by, of the dip and intensity, made at sea between Falmouth and the Falkland Islands, 142.

Sun's atmosphere, possible indication of absorptive action in the, 29.

T.

Tables of the elevation or depression of the surface of the sea above or below mean water at all hours of the tide, for Plymouth and Liverpool, 261; of observations at Plymouth when the surface passes certain fixed lines near mean water; and the calculated time of high water, hence obtained, compared with the observed time, 262.

Table of tide observations, at Petropaulofsk, 169; Port de Lloyd, 172; Port de la Coquille, 173; Sitkhae, 174.

— of, observations of the dip and intensity made at sea between Falmouth and the Falkland Islands, 142.

— of observations of the dip and intensity made at sea in a voyage from England to Australia, 146.

- Table of observations of the dip, in a voyage from England to Australia, 147.*
 — of observations of the intensity, in a voyage from England to Australia, 150.
 — of diameters of primitive fasciculi of voluntary muscle, 460.
 — of measurements of ova of the Rabbit, 567.
- Tables of the results of experiments on the strength of pillars of cast iron, wrought iron, steel and timber, 431—453.*
- Telescope (reflecting), an account of experiments on the, 503; method of forming a large speculum of several castings, 505; process of casting, 509; processes of grinding and polishing 514; performance of one three feet in diameter, 525.*
- Terrestrial magnetism, contributions to, 129. § 1. Lines of inclination and intensity in the Atlantic Ocean, 129. § 2. Lines of intensity between the Cape of Good Hope and Australia, 140.*
- Tides, additional note to the eleventh series of researches on the, 161.*
 — table of, at Petropaulofsk, 169; at Port de Lloyd, 172; at Port de la Coquille, 173; at Sitkhæ, 174.
 — researches on the. Twelfth series: On the laws of the rise and fall of the sea's surface during each tide, 255.
- Timber, strength of pillars of, 421, 424; crushing strength, 429; table of results of experiments on the strength of pillars, 453.*
- TREUTER (Dr.). Letters of, to THOMAS MACLEAR, Esq., on the fall of the Cold Bokkeveld meteorolite, 181.*
- Tunica granulosa, changes in the, immediately after fecundation, 536.*

U.

Uterus, ova found in the, of the Rabbit, 565.

V.

- Vegetable colours, effect of the spectrum on certain, 33.*
- Voltaic battery. An account of experiments made with the view of ascertaining the possibility of obtaining a spark before the circuit is completed, 183.*
- Voltaic circles, inactive conducting, 69; active and inactive, 84—90; differences in the order of the metallic elements of, 112; active, without metallic contact, 114.*
- Voltaic electricity, contact theory of, 62; chemical theory of, 64; chemical and contact theories of, compared, 77.*
- Voltaic pile, on the source of power in the, 61, 93.*

W.

- WHEWELL (The Rev. WILLIAM). Additional note to the eleventh series of researches on the tides, 161.*
 —. Researches on the tides. Twelfth series: On the rise and fall of the sea's surface during each tide, 255.
- WICKHAM (Commander, R.N.). Table of observations by, of the dip, in a voyage from England to Australia, 147; of the intensity, 150.*

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METEOROLOGICAL JOURNAL,

KEPT BY THE ASSISTANT SECRETARY,

AT THE APARTMENTS OF THE

ROYAL SOCIETY,

BY ORDER OF

THE PRESIDENT AND COUNCIL.

OBSERVANDA.

Height of the Cistern of the Barometer above the plinth at Waterloo Bridge....83 feet 2 inches.

.....above the mean level of the sea 97 feet.

Height of the receiver of the Rain Gauge above the court of Somerset House ...79 feet.

The External Thermometer is 2 feet higher than the Barometer Cistern.

The Thermometers are graduated to Fahrenheit's scale.

The Barometer is divided into inches and tenths.

The Hours of Observation are of Mean Time, the day beginning at Midnight.

The *daily* observations of the Barometer are *not* corrected.

The *monthly means* are corrected for capillarity and temperature by the Table contained in Mr. Baily's paper in *Phil. Trans.* for 1837.

METEOROLOGICAL JOURNAL FOR JANUARY AND FEBRUARY, 1840.

		9 o'clock, A.M.			3 o'clock, P.M.			External Thermometers.			Wind at 9 A.M.		REMARKS.				
		Barometer corrected.		Alt.	Barometer corrected.		Alt.	Fahrenheit.		Self-registering	Direction of Wind						
		Flint Glass.	Queen Glass.		Flint Glass.	Queen Glass.		A.M.	P.M.	F.	W.						
W	1	29.724	29.718	45.9	29.728	29.724	47.6	44	02.1	49.8	51.8	44.3	50.5	S	(A.M. Overcast—light rain and wind. P.M. Fine—light clouds.		
T	2	29.738	29.732	47.9	29.818	29.810	49.2	43	01	47.6	47.6	47.6	48.0	SW	(A.M. Fine—clouds and wind throughout the day. Ev. Overcast—rain.		
F	3	30.000	29.994	45.9	29.992	29.984	46.7	40	01	47.2	47.2	41.8	43.5	025	W	(A.M. Fine—light clouds and wind. P.M. Cloudy—light rain.	
S	4	29.956	29.950	45.5	29.888	29.882	44.7	40	01	47.0	39.7	39.2	40.6	072	NE	Overcast—rain and wind throughout the day, as also the evening.	
O	5	29.896	29.890	42.2	29.878	29.874	42.0	37	01	31.3	36.3	37.4	36.7	205	NE	Fine—light clouds and wind throughout the day. Evening, fine.	
M	6	29.960	29.954	38.6	30.100	29.992	38.6	32	01	33.6	36.6	36.6	36.6	000	W	Fine—light clouds and wind, with sharp frost during the morning.	
T	7	29.282	29.276	34.0	30.218	30.212	34.0	27	02	29.9	31.9	30.9	32.0	000	ENE	Evening, Cloudy—light rain.	
F	8	29.156	29.150	34.0	30.130	30.122	34.1	27	01	22.8	30.7	22.3	29.4	000	SW	Fine—light clouds and wind, with sharp frost. Ev. Overcast—sharp frost and clear-sky frost.	
T	9	29.424	29.416	32.0	30.238	30.232	32.4	28	01	33.2	36.2	32.3	32.8	000	SE	Light fog—sharp frost throughout the day. Ev. Overcast—rain.	
F	10	30.276	30.270	36.3	30.482	30.476	36.9	26	05	33.2	34.7	32.6	34.8	000	SE	Fine—light clouds and wind throughout the day. Ev. Fine & clear.	
S	11	30.516	30.510	32.8	30.478	30.470	33.6	27	01	37.4	34.7	32.0	37.2	000	SE	(A.M. Fine—light clouds and wind throughout the day. Evening, Fine and clear—sharp frost.	
O	12	29.866	29.860	32.5	30.254	30.248	34.0	27	01	31.5	38.0	27.8	35.3	000	SE	Fine—light clouds and wind throughout the day. Ev. Fine and clear.	
M	13	29.844	29.838	36.8	30.028	30.022	36.3	28	01	34.9	40.7	31.4	38.3	000	SE	(A.M. Fine—light clouds and wind. P.M. Overcast—light rain and wind.	
T	14	29.912	29.906	36.8	30.054	30.048	36.3	28	02	32.9	41.1	32.9	41.5	000	SE	Overcast—light rain throughout the day. Evening, Very light rain.	
F	15	30.142	30.136	41.0	30.054	30.048	43.9	39	01	40.2	43.8	40.2	44.7	000	SSW	Overcast—brisk wind throughout the day. Ev. Light rain—high wind.	
T	16	29.718	29.712	43.2	29.738	29.730	44.3	39	04	40.7	45.8	40.8	46.8	044	SW	Fine—very light clouds & wind throughout the day. Ev. Lightly mist.	
F	17	29.496	29.494	43.3	29.574	29.568	43.9	40	01	42.5	42.8	40.8	46.6	127	S	Overcast—rain, fog & wind throughout the day. Ev. Fine & clear.	
S	18	29.472	29.464	40.9	29.764	29.758	41.7	36	01	36.3	44.8	34.2	43.8	033	S	(A.M. Fine—light clouds and wind. P.M. Overcast—light rain and wind.	
O	19	29.936	29.930	45.0	29.366	29.362	47.5	44	01	49.4	51.4	35.6	50.7	122	S	W. Heavy showers—high wind. Ev. Cloudy—high wind.	
M	20	29.984	29.978	44.8	29.212	29.206	46.4	41	01	42.6	45.6	41.4	54.2	282	SW	(A.M. Overcast—light rain—high wind, also during the morning.	
T	21	29.684	29.678	46.7	29.662	29.656	47.9	43	02	48.8	49.9	45.0	53.2	133	S	(A.M. Overcast—high wind, also throughout the night. P.M. Fine—light clouds and	
T	22	29.684	29.678	46.7	29.662	29.656	47.9	43	02	48.8	49.9	45.0	53.2	133	S	(A.M. Overcast—high wind, also throughout the night. P.M. Fine—light clouds and	
T	23	29.808	29.802	45.2	29.684	29.678	47.4	41	02	45.7	47.7	52.9	41.2	51.4	022	S var.	(A.M. Overcast—light rain—high wind. P.M. Dark heavy clouds and
F	24	29.346	29.340	50.8	29.866	29.860	51.4	47	03	52.0	52.4	47.4	53.5	000	S var.	Overcast—rain—high wind throughout the day, as also the evening.	
S	25	29.316	29.310	46.7	29.384	29.380	46.9	42	03	43.0	43.5	39.6	53.3	394	S	(A.M. Fine—light clouds & wind throughout the day. Ev. Cloudy—high wind.	
O	26	29.838	29.834	47.3	29.866	29.862	48.4	40	02	50.5	47.3	40.6	52.7	48	S var.	(A.M. Fine—light clouds and wind. P.M. Overcast—light rain and wind.	
M	27	29.424	29.436	44.3	29.214	29.206	45.3	38	02	37.8	43.7	37.0	46.5	048	SW	(A.M. Overcast—light rain—high wind, also during the morning.	
T	28	29.500	29.494	44.3	29.214	29.206	45.3	38	02	37.8	43.7	37.0	46.5	048	SW	(A.M. Overcast—light rain—high wind, also during the morning.	
F	29	29.496	29.490	45.0	29.740	29.734	45.8	41	02	46.8	45.7	42.6	45.5	272	W	(A.M. Overcast—light rain—high wind. P.M. Fine—light showers	
T	30	29.938	29.932	42.0	29.872	29.866	42.3	36	01	34.4	41.8	34.6	35.0	000	SSW	A.M. Light fog & wind. P.M. Fine—light clouds. Ev. Overcast—rain.	
F	31	29.574	29.568	44.0	29.582	29.528	45.9	40	01	42.4	46.8	34.8	44.3	044	S	(A.M. Overcast—light rain. P.M. Fine—light clouds and wind.	
MEAN.		29.806	29.798	11.8	29.781	29.774	42.6	37.0	01.9	40.4	43.5	36.9	43.5	Sam. 2,633		Mean Barometer corrected	G. A.M. 3.30 P.M. 3.30 F. 30.007 3

METEOROLOGICAL JOURNAL FOR MARCH AND APRIL, 1840.

1840.	9 o'clock, A.M.			3 o'clock, P.M.			External Thermometers.				Rain in Inches. If at all, at what hour.	Direction of the Wind. If at all, at what hour.	REMARKS.		
	Barometer uncorrected.		Alt. Ther.	Barometer uncorrected.		Alt. Ther.	Fahrenheit.		Self-registering.						
	Pilot Glass.	Crown Glass.		Pilot Glass.	Crown Glass.		9 A.M.	3 P.M.	Lowest.	Highest.					
○	1.30.374	30.366	36.2	30.332	30.328	37.0	28	03.2	32.7	36.0	30.7	33.2	ENE	(Fine—light clouds—brisk wind throughout the day. Ex. Fine—starlight night.)	
M	2.30.438	30.430	35.5	30.410	30.410	37.2	25	03.6	36.8	42.7	31.2	37.4	NE	Fine—light clouds & wind throughout the day. Fine—starlight night.	
T	3.30.430	30.422	38.0	30.360	30.354	40.3	32	02.4	38.8	45.9	35.0	39.6	E	Starlight night.	
W	4.30.386	30.380	37.0	30.348	30.342	38.9	30	03.2	35.8	38.4	32.8	36.3	NE	(A.M. Cloudy—brisk wind. P.M. Fine—light clouds—brisk wind.	
T	5.30.408	30.402	36.9	30.366	30.358	39.2	29	03.0	35.4	43.6	32.6	36.0	E	Fine—light clouds & wind throughout the day. Evening, Fine—starlight night.	
F	6.30.454	30.446	38.3	30.442	30.434	40.4	30	03.0	36.7	48.2	32.0	37.2	ENE	(A.M. Light fog and wind. P.M. Fine—light clouds. Evening, Fine—starlight night.)	
S	7.30.564	30.556	38.6	30.562	30.554	40.6	32	02.7	37.2	47.2	32.7	37.8	N	(A.M. Light fog & wind. P.M. Fine—light clouds. Ex. Fine—starlight night.)	
C	8.30.656	30.650	38.9	30.604	30.598	41.0	30	02.2	37.7	50.6	32.7	39.0	N	Fine—light clouds & wind throughout the day. Ex. Fine—starlight night.	
M	9.30.640	30.634	38.8	30.578	30.570	41.4	31	02.8	37.2	50.3	31.7	38.0	N	Starlight night.	
T	10.30.392	30.386	41.7	30.304	30.296	43.7	33	02.5	39.0	52.3	35.3	47.4	NNW	(Cloudy—light wind (slight rain early) throughout the day. Evening, Overcast—very slight rain.)	
W	11.30.284	30.276	45.2	30.304	30.298	45.8	40	02.7	42.8	45.0	38.6	53.7	N	(A.M. Light fog and wind. P.M. Fine—light clouds. Ex. Overcast.)	
T	12.30.274	30.266	44.4	30.218	30.210	46.4	38	03.0	43.8	48.7	40.8	46.3	NNW	(A.M. Light fog and wind. P.M. Fine—light clouds. Ex. Overcast.)	
F	13.30.106	30.098	45.3	30.014	30.006	47.9	39	03.0	45.0	50.0	40.7	46.0	NW	(A.M. Lightly overcast—light wind. P.M. Fine—light clouds.	
S	14.30.050	30.044	46.0	30.036	30.028	48.7	40	03.6	45.8	49.3	42.0	46.5	WNW	Overcast—light brisk wind throughout the day. Evening, Cloudy.	
○	15.29.774	29.968	45.7	29.840	29.836	47.0	38	02.5	43.2	47.4	40.4	43.8	N	(A.M. Light fog and wind. P.M. Overcast—light rain. Ex. Fine—light clouds & wind throughout the day. Ex. Fine—starlight night.)	
M	16.30.042	29.954	45.8	29.818	29.810	46.6	39	02.3	42.4	44.6	42.0	43.0	.133	NE	(A.M. Overcast—light wind. P.M. Fine—light clouds & wind. Ex. Overcast.)
T	17.30.282	29.976	44.8	29.844	29.836	45.2	29	04.5	39.8	45.0	37.3	40.6	N	Fine—light clouds and wind throughout the day. Evening, Overcast—light rain.	
W	18.30.174	30.166	43.9	30.124	30.116	45.8	38	02.5	41.7	45.8	39.2	45.7	NNW	(A.M. Overcast—light wind. P.M. Fine—light clouds & wind throughout the day. Evening, Dark heavy clouds.)	
T	19.30.198	30.190	44.6	30.230	30.222	46.2	37	03.1	41.3	44.4	40.0	42.0	N	Cloudy—light wind throughout the day. Evening, Cloudy.	
F	20.30.318	30.312	43.7	30.268	30.260	45.8	37	02.5	41.3	47.9	36.4	41.8	WNW	(A.M. Overcast—light wind throughout the day. Ex. Fine and clear.)	
S	21.30.412	30.404	45.8	30.410	30.402	44.4	31	05.1	37.7	43.7	32.6	39.3	NW	(A.M. Fine—light clouds—brisk wind throughout the day. Evening, Cloudy—brisk wind.)	
○	22.30.106	30.100	42.9	30.204	30.214	44.0	33	03.0	39.7	43.4	42.0	42.0	NW	(A.M. Fine—light clouds and wind. P.M. Overcast—light wind and wind.	
M	23.29.998	29.992	43.8	30.030	30.024	43.8	37	03.0	39.0	38.3	37.4	46.4	.022	NW	Overcast—brisk wind throughout the day, with occasional snow and rain. Evening, Cloudy.
T	30.152	30.144	43.5	30.138	30.130	41.8	32	03.4	36.7	38.8	33.0	38.2	.038	N var.	(A.M. Fine—light clouds & wind (occasionally). P.M. Fine—light clouds—brisk wind. Evening, Fine and moonlight.)
W	22.30.298	29.292	40.5	30.286	30.282	40.0	39	03.1	37.4	35.6	32.0	41.0	NNW	(A.M. Fine—light clouds & wind throughout the day. Evening, Fine and moonlight.)	
T	26.30.324	30.316	38.5	30.246	30.238	40.6	30	03.1	35.3	37.9	30.9	40.3	.022	N	Overcast—light wind throughout the day, with occasional snow. Evening, Cloudy—brisk wind.
F	27.30.124	30.116	40.5	30.106	30.098	42.0	32	04.3	37.4	40.2	34.0	38.2	N	Overcast—brisk wind throughout the day, so also the evening.	
S	28.30.116	30.108	39.7	30.028	30.020	40.8	32	03.5	38.7	40.5	35.8	39.5	NW	Overcast—light wind throughout the day, so also the evening.	
○	29.788	29.782	40.7	29.746	29.742	42.0	33	02.5	39.6	46.2	38.2	42.0	W	(Overcast—light fog and wind throughout the day. Evening, Fine—starlight night.)	
M	30.284	29.886	45.3	29.900	29.894	45.2	36	03.6	46.7	49.3	38.2	48.3	S	(A.M. Fine—light clouds and wind. P.M. Cloudy—light wind. Evening, Fine—starlight night.)	
T	31.284	29.832	46.0	29.818	29.810	46.8	40	03.3	46.8	47.8	45.2	47.6	NNW	(Overcast—very rain, to light wind throughout the day, so also the evening.)	
MEAN.	30.248	30.241	41.8	30.214	30.207	43.1	33.5	03.1	39.7	44.7	35.9	41.7	Sum.	215	Mean Barometer corrected { 9 A.M. 3 P.M. F. 30.216 .. 30.179 C. 30.208 .. 30.171
W	1.29.664	29.656	46.2	29.606	29.600	47.9	42	02.4	44.4	46.3	43.9	47.0	.072	S	Overcast—light wind throughout the day. Evening, Slight rain.
○	2.29.720	29.714	48.5	29.756	29.746	49.0	40	03.8	46.3	54.0	39.3	47.2	E	Fine—light clouds and wind throughout the day. Ex. Overcast.	
F	3.30.024	30.016	46.8	29.994	29.988	49.9	42	03.7	42.3	47.9	41.0	50.0	NNE	(A.M. Lightly overcast—light wind. P.M. Fine—light clouds and wind.	
S	4.29.960	29.952	45.8	29.924	29.916	46.7	37	03.6	39.8	46.5	34.4	49.0	N	(A.M. Fine—light clouds and wind. P.M. Cloudy. Evening, Fine—light clouds and wind throughout the day. Evening, Fine—light clouds and wind throughout the day.	
○	5.30.044	30.036	43.8	30.004	30.000	48.0	39	04.0	45.2	54.8	39.6	45.8	NW	(A.M. Fine—light clouds and wind throughout the day. Evening, Fine—light clouds and wind throughout the day.	
M	6.29.798	29.792	51.9	29.634	29.628	50.2	40	04.7	49.3	53.2	38.8	55.2	N	(A.M. Fine—light clouds and wind throughout the day. Evening, Fine—light clouds and wind throughout the day.	
T	7.29.558	29.552	50.7	29.628	29.622	49.7	41	03.5	43.4	49.3	38.9	44.4	.033	NNW	(A.M. Fine—light clouds—high wind throughout the day. Evening, Overcast—light showers.
W	8.29.998	29.992	47.5	30.028	30.020	46.3	38	04.0	41.5	44.7	37.8	42.2	.116	N	(A.M. Fine—light clouds—high wind, so also throughout the night.
T	9.30.264	30.256	45.0	30.302	30.294	46.7	37	03.3	42.3	47.7	35.3	43.3	NNW	(A.M. Fine—light clouds—high wind, so also throughout the night.	
S	10.30.408	30.400	48.2	30.244	30.236	48.0	34	05.0	44.7	51.4	36.4	45.4	NNW	(A.M. Cloudy—light wind. Evening, Fine and starlight.)	
S	11.30.258	30.250	50.0	30.134	30.128	48.8	36	05.7	46.8	57.4	35.4	47.7	S	(A.M. Fine—light clouds—high wind throughout the day. Evening, Fine and moonlight.)	
○	12.30.058	30.050	48.0	30.004	29.998	51.0	43	03.0	47.2	54.9	43.8	48.0	SSW	(A.M. Overcast—light wind. P.M. Fine—light clouds. Ex. Fine & clear.)	
T	13.29.918	29.912	49.2	29.838	29.830	52.0	38	03.7	45.0	58.8	39.7	46.0	NW	(A.M. Light fog and wind. P.M. Fine—light clouds. Ex. Fine & clear.)	
W	14.29.808	29.800	52.3	29.786	29.780	52.3	40	03.4	46.9	62.0	41.6	48.7	N	(A.M. Fine—light fog & wind. P.M. Fine—light clouds. Ex. Fine & moonlight.)	
T	15.29.942	29.936	54.4	29.936	29.928	54.6	40	05.2	55.7	64.3	44.7	56.3	ENE	(A.M. Fine—light fog & wind. P.M. Fine—light clouds & wind. Evening, Fine and moonlight.)	
○	16.30.108	30.102	60.2	30.086	30.078	56.3	42	08.6	55.7	65.4	44.6	56.4	NW	(A.M. Fine—light fog & wind. P.M. Fine—light clouds—light rain. Evening, Fine and moonlight.)	
T	17.30.188	30.182	57.8	30.108	30.106	54.4	44	04.4	50.5	58.3	40.9	51.6	.033	N	(A.M. Fine—light fog & wind. P.M. Fine—light clouds & wind. Ex. Fine & moonlight.)
S	18.30.040	30.034	60.8	29.958	29.950	53.2	43	02.8	47.0	59.6	38.2	47.7	N	(A.M. Fine—light fog & wind. P.M. Fine—light clouds & wind. Ex. Fine & moonlight.)	
○	19.29.922	29.914	45.5	29.850	29.846	52.3	40	02.7	42.8	59.7	39.0	43.5	NW	(A.M. Light fog & wind. P.M. Fine—light clouds. Ex. Fine & moonlight.)	
M	20.29.898	29.892	56.3	29.850	29.842	54.4	41	06.0	51.2	63.4	42.0	51.6	ENE	(A.M. Light fog & wind. P.M. Fine & cloudless. Ex. Fine & starlight.)	
T	21.30.074	30.066	56.0	30.076	30.068	56.4	44	04.5	53.8	60.7	47.0	54.8	S	Cloudy—light wind throughout the day. Evening, Fine & starlight.	
W	22.30.234	30.226	55.8	30.266	30.258	57.9	49	05.5	58.2	63.0	49.3	58.8	NW	(A.M. Cloudy—light wind throughout the day, so also the evening.)	
T	23.30.348	30.342	59.2	30.304	30.296	59.0	50	06.0	58.4	65.2	50.0	59.2	W var.	(A.M. Fine—light clouds—brisk wind throughout the day. Evening, Fine—light clouds—brisk wind throughout the day. Evening, Fine—light clouds—brisk wind throughout the day.	
○	24.30.298	30.290	67.0	30.212	30.204	61.5	51	05.8	58.3	68.3	50.4	58.8	N	(A.M. Cloudy—light wind throughout the day, so also the evening.)	
S	25.30.174	30.166	64.7	30.120	30.112	62.0	58	07.2	61.8	73.0	50.7	66.4	N	(A.M. Light fog & wind. P.M. Fine & cloudless—light wind. Evening, Fine and starlight.)	
○	26.30.312	30.304	67.8	30.284	30.276	63.4	55	05.9	60.5	70.4	51.5	66.2	E	(A.M. Light fog & wind. P.M. Fine—light clouds & wind. Evening, Fine and starlight.)	
T	27.30.356	30.350	65.3	30.300	30.292	64.2	55	07.2	62.5	69.3	51.2	66.8	N	(A.M. Light fog & wind. P.M. Fine & cloudless—light wind. Evening, Fine and starlight.)	
M	28.30.300	30.296	68.8	30.240	30.234	63.5	52	07.5	59.7	72.7	48.7	67.0	ENE	(A.M. Fine & cloudless—light wind throughout the day. Ex. Fine & starlight.)	
W	29.30.298	29.290	67.0	30.260	30.252	64.6	52	07.5	67.0	72.3	54.0	67.0	NE	(A.M. Fine—light clouds and wind. P.M. Fine & cloudless—light wind. Evening, Fine & moonlight.)	
T	30.30.324	30.316	65.2	30.272	30.264	64.1	51	08.0	59.2	69.2	52.0	72.2	NW	(A.M. Fine—light clouds—high wind throughout the day, with light breeze. Evening, Lightly overcast.)	
MEAN.	30.077	30.069	55.2	30.037	30.030	54.3	49.6	05.1	50.9	59.5	43.3	53.5	Sum.	254	Mean Barometer corrected { 9 A.M. 3 P.M. F. 30.050 .. 29.972 C. 30.040 .. 29.963

METEOROLOGICAL JOURNAL FOR MAY AND JUNE, 1840.

1840,	5 o'clock, A.M.			5 o'clock, P.M.			External Thermometers.				Remarks.			
	Barometer uncorrected.		Alt. Ther.	Barometer uncorrected.		Alt. Ther.	Fahrenheit.		Self-registering.					
	First Glass.	Crown Glass.		First Glass.	Crown Glass.		5 A.M.	5 P.M.	Lowest.	Highest.				
F 130.356	30.348	58.6	30.314	30.306	60.3	50	53.2	48.7	61.0	48.2	NNE	A.M. Lightly overcast—light wind. P.M. Fine and cloudless—light wind. Clearing.		
S 230.288	30.280	61.8	30.216	30.208	60.2	52	55.1	55.4	65.7	45.2	E	Fine—clouds and wind throughout the day. Ex. Fine & starlight.		
3 30.172	30.166	73.0	30.110	30.104	61.0	49	59.6	59.3	66.1	46.3	E	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and starlight.		
M 430.126	30.118	65.2	30.058	30.050	61.2	49	58.1	58.3	61.7	48.7	E	Fine and cloudless—light wind throughout the day. Evening, Fine and starlight.		
T 529.912	29.904	59.6	29.866	29.858	60.3	49	55.4	55.7	62.3	45.4	NW	Cloudy—light wind throughout the day, so also the evening.		
W 629.888	29.880	59.3	29.834	29.826	60.7	51	55.3	54.7	63.2	49.0	011 SW	A.M. Fine—light clouds and wind. P.M. Cloudy—light wind. Evening, Overcast—light shower.		
T 729.760	29.752	58.0	29.728	29.722	61.3	51	55.3	57.3	64.7	49.7	011 SW	Cloudy—light wind throughout the day, so also the evening.		
F 829.706	29.700	65.8	29.646	29.638	62.9	54	55.9	59.7	65.3	54.7	SE	A.M. Cloudy—very light rain and wind. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.		
S 929.524	29.516	59.8	29.452	29.448	62.7	53	55.0	55.0	66.0	54.0	063 SE	A.M. Overcast—light rain and wind. P.M. Cloudy—light rain. Evening, Overcast—light rain.		
1029.402	29.408	64.7	29.400	29.394	64.2	53	56.9	59.8	66.3	53.3	450 S	Cloudy—light wind throughout the day. Ex. Overcast—light rain.		
M 1129.534	29.526	59.3	29.586	29.578	60.2	53	56.9	59.8	64.7	51.6	133 NW	Overcast—very light, mist and wind throughout the day. Ex. Overcast.		
T 1229.670	29.664	58.3	29.670	29.664	59.9	52	53.2	53.7	55.3	51.2	ENE	Overcast—light rain.		
W 1329.662	29.654	56.2	29.650	29.644	59.7	52	51.5	53.3	61.8	49.8	180 N	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.		
T 1429.678	29.672	59.9	29.618	29.612	61.3	52	56.2	59.3	65.7	51.9	N	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.		
F 1529.414	29.408	59.3	29.422	29.414	60.0	55	53.5	53.7	56.3	53.2	450 NW	Overcast—light wind, with occasional rain throughout the day—light rain.		
S 1629.404	29.400	63.2	29.362	29.356	60.7	53	57.1	57.8	60.7	51.4	447 S var.	A.M. Cloudy—light rain and wind, with occasional showers. P.M. Fine—light clouds and wind. Evening, Overcast.		
1729.374	29.366	57.9	29.394	29.390	59.9	52	54.9	55.7	57.5	50.2	033 S	Cloudy, with showers throughout the day. Evening, Heavy rain—clouds—rain.		
M 1829.626	29.620	59.2	29.724	29.716	60.0	51	56.1	55.8	59.4	48.3	250 W	Cloudy—light wind throughout the day. Evening, The like.		
T 1930.080	30.072	55.2	30.142	30.134	56.3	49	51.8	52.7	50.3	46.6	NNW	Lightly overcast—light wind throughout the day. Ex. Fine & clear.		
W 2030.052	30.048	56.4	30.034	30.026	55.8	48	50.3	52.3	57.2	41.3	N	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds and wind. Evening, Clear.		
T 2130.216	30.210	69.6	30.236	30.228	56.0	49	57.2	57.8	52.8	41.6	066 NW	Cloudy—light rain.		
F 2230.344	30.338	55.0	30.340	30.334	55.7	45	58.9	58.8	55.3	44.3	NW	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds and wind. Evening, Clear.		
S 2330.356	30.350	66.2	30.284	30.276	59.0	46	55.0	57.7	64.4	44.2	NW	A.M. Fine & cloudless—light wind. P.M. Overcast. Ex. Fine & starlight.		
2430.172	30.164	59.2	30.086	30.080	61.0	53	56.2	61.5	64.3	53.3	SW var.	Lightly overcast—light rain, so also throughout the night. P.M. Cloudy—light rain and wind. Evening, Fine and starlight.		
M 2530.890	29.890	59.9	29.802	29.796	61.4	55	54.0	58.8	60.8	56.3	183 S	A.M. Overcast—light rain, so also throughout the night. P.M. Cloudy—light rain and wind. Evening, Fine and starlight.		
T 2629.844	29.838	58.3	29.758	29.750	60.2	50	54.5	54.6	61.8	49.4	S	Overcast, with occasional showers and light wind throughout the day. Evening, Fine and starlight.		
W 2730.650	30.646	70.5	30.066	30.068	61.7	51	57.1	56.7	65.3	45.6	063 SW	Fine—light clouds and wind throughout the day. Ex. Fine & starlight.		
T 2829.926	29.920	71.6	29.896	29.890	63.2	52	58.9	60.8	71.8	50.9	SWW	Fine—light clouds and wind throughout the day. Ex. Fine & starlight.		
F 2930.088	30.084	70.4	30.194	30.186	65.2	52	61.0	60.7	65.7	55.0	NW	Clear.		
S 3030.398	30.392	64.9	30.364	30.356	64.7	54	57.9	61.4	69.3	51.4	SW	A.M. Cloudy—light rain and wind. P.M. Fine—light clouds and wind. Evening, Fine and starlight.		
3130.400	30.392	71.8	30.326	30.320	66.7	56	59.2	63.8	73.2	56.6	S	Fine—light clouds and wind throughout the day. Ex. Fine & starlight.		
MEAN.	29.911	29.904	62.2	29.912	29.880	60.8	51.1	56.0	56.3	62.1	49.6	Sum.	2.329	
												Mean Barometer corrected	29.915 - 29.920 29.925 - 29.930 29.935 - 29.940	
M 130.212	30.206	74.7	30.090	30.082	68.7	58	59.9	66.7	77.8	55.7	83.0	S	Fine and cloudless throughout the day. Evening, Fine & starlight.	
T 229.806	29.800	70.3	29.868	29.860	65.9	60	55.9	64.8	54.8	60.5	82.7	022 NW	A.M. Cloudy—light rain and wind. P.M. Overcast—light rain.	
W 330.106	30.100	73.7	30.148	30.140	64.3	48	58.3	56.8	59.7	48.8	66.2	294 NW	Fine—light clouds and wind throughout the day. Ex. Fine & starlight.	
T 430.198	30.190	58.8	30.150	30.142	62.6	50	56.4	57.7	58.5	53.5	61.0	NW var.	Overcast—light wind throughout the day, so also the evening.	
F 530.040	30.034	60.3	29.978	29.970	61.3	54	56.4	57.7	64.3	53.5	65.8	047 W	A.M. Overcast—light rain and wind during the night. P.M. Overcast.	
S 629.938	29.932	72.8	29.896	29.888	64.2	54	57.4	61.8	71.3	52.2	66.2	172 E	Fine—light clouds and wind throughout the day. Evening, Fine and starlight.	
T 730.018	30.012	74.6	30.030	30.024	67.0	58	58.4	63.2	69.4	56.8	72.3	333 SW var.	Fine—light clouds and wind throughout the day. Evening, Fine and starlight.	
M 830.072	30.068	71.0	30.030	30.006	66.3	53	59.9	63.7	69.8	52.5	73.8	SE	Fine—light clouds and wind throughout the day. Ex. Overcast.	
T 930.008	30.000	68.3	29.986	29.978	69.0	60	58.0	67.3	72.2	60.8	72.6	SE	Lightly overcast throughout the day. Ex. Fine and starlight.	
W 1030.014	30.006	72.7	30.014	30.006	69.3	59	58.3	64.8	67.4	59.5	74.4	SE	A.M. Fine—light clouds and wind. P.M. Cloudy—light rain.	
T 1130.100	30.094	71.7	30.042	30.034	70.5	55	58.0	64.3	71.7	52.8	71.7	S	Overcast, Fine and starlight.	
F 1229.998	29.992	66.8	29.914	29.906	69.3	60	56.3	64.6	67.7	61.2	73.3	S	Cloudy—light wind throughout the day. Evening, Overcast.	
S 1329.992	29.986	67.8	29.976	29.968	68.7	57	57.4	63.5	67.7	59.0	71.2	W	A.M. Cloudy—light rain. P.M. Fine—light clouds and wind. Evening, Clear.	
1430.096	30.088	77.5	29.986	29.980	70.0	59	58.7	65.7	69.0	56.5	72.8	S	A.M. Fine—light clouds and wind. P.M. Lightly overcast. Ex. Fine.	
M 1530.054	30.050	72.9	29.976	29.970	68.7	59	58.5	64.8	70.7	54.4	75.3	SWW	Fine—light clouds and wind throughout the day. Ex. Fine and clear.	
T 1629.868	29.862	75.3	29.866	29.858	69.8	61	58.5	66.8	71.6	59.6	74.3	S	A.M. Fine—light clouds and wind—rain, with high wind during the night. P.M. Fine and clear. Ex. Heavy rain—clouds—rain.	
W 1729.836	29.832	76.8	29.816	29.808	69.9	58	58.9	64.8	67.6	59.5	74.3	094 S	A.M. Fine—light clouds and wind—rain, with high wind during the night. P.M. Fine and clear. Ex. Heavy rain—clouds—rain.	
T 1829.870	29.866	75.2	29.920	29.912	68.0	53	58.9	61.8	66.3	52.2	71.6	347 NW	A.M. Overcast—light rain and wind throughout the day. Ex. Cloudy.	
F 1929.970	29.962	64.0	29.900	29.894	64.8	58	57.5	61.7	60.4	53.0	67.7	S	Fine and starlight.	
S 2030.150	30.146	75.0	30.184	30.176	66.0	54	58.0	61.2	67.7	50.6	72.6	111 W	A.M. Cloudy—light rain. P.M. Fine—light clouds and wind. Evening, Clear.	
2130.198	30.190	66.3	30.084	30.080	66.0	56	59.0	65.0	71.2	56.6	69.8	S	A.M. Cloudy—light rain. P.M. Fine—light clouds and wind. Evening, Clear.	
T 2229.834	29.832	72.7	29.796	29.790	68.3	55	58.5	64.8	68.7	56.2	75.3	S	Fine—light clouds and wind throughout the day—rain early.	
F 2329.736	29.730	70.0	29.676	29.668	67.3	52	58.7	62.0	66.0	53.5	71.7	SW	Fine—light clouds and wind throughout the day. Ex. Fine and clear.	
W 2429.838	29.832	78.0	29.874	29.874	65.3	50	57.7	64.3	59.3	49.4	67.6	091 NW	Fine—light clouds and wind throughout the day. Ex. Cloudy.	
T 2530.010	30.002	63.2	30.014	30.006	62.8	48	57.9	57.4	59.5	49.0	66.6	NW	Cloudy—light wind throughout the day. Ex. Fine and starlight.	
F 2630.154	30.148	66.7	30.166	30.158	63.0	50	57.6	61.3	62.2	50.7	66.8	NW	Cloudy—light showers and wind. P.M. Overcast. Ex. The like.	
S 2730.196	30.190	63.6	30.162	30.154	64.9	54	57.0	63.7	68.7	56.2	65.4	116 W	A.M. Fine—light clouds and wind. P.M. Cloudy. Ex. Very slight rain.	
2830.092	30.086	65.0	30.064	30.060	66.0	55	57.6	64.8	68.6	59.7	70.4	NW	Cloudy—light wind throughout the day. Evening, Overcast.	
T 2930.100	30.094	63.6	30.070	30.062	66.8	55	58.0	61.4	68.8	56.6	70.6	S	Overcast—light wind throughout the day. Ex. Fine and starlight.	
T 3030.018	30.010	66.7	29.986	29.978	67.3	59	56.3	63.3	64.8	57.8	73.0	S	A.M. Overcast—light rain. P.M. Light rain. Ex. Fine & starlight.	
MEAN.	30.017	30.011	70.0	29.992	29.985	66.7	55.5	57.9	62.6	66.8	53.5	71.2	Sum.	1.760
												Mean Barometer corrected	29.915 - 29.920 29.925 - 29.930 29.935 - 29.940	

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- PLUTARCHUS. Cheronensis Liber de Regum atque Imperatorum scitè dictis quæ Apophthegmata nuncupantur. Rec. et ornav. St. Pemberton. 8vo. *Oxonii* 1768. G. Pemberton, Esq., F.R.S.
- PORTLOCK (J. E.) Address delivered at the Eighth Annual Meeting of the Geological Society. 8vo. *Dublin* 1839. The Author.
- POWELL (Rev. B.) Additional Observations for determining the Refractive Indices for definite rays of the Solar Spectrum in several media. 8vo. *Oxford* 1838. The Author.
- Second Supplement to Observations for determining the Refractive Indices. 8vo. *Lond.* 1839.
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- PRITCHARD (Rev. C.) A Treatise on the Theory of Statical Couples, to which is added a simple method of investigating the Ellipticity of the Earth considered as a Heterogeneous Spheroid. 8vo. *Lond.* 1837. The Author.
- QUETELET (A.) Annuaire de l'Observatoire de Bruxelles, pour 1840. 18mo. *Bruxelles* 1840. The Author.
- Catalogue des Principales Apparitions d'Étoiles Filantes. 4to. *Bruxelles* 1839.
- Correspondance Mathématique et Physique. 3^{ème} Série. Tom. III. Liv. 2. Juillet 1839. 8vo. *Bruxelles* 1839.
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- Sur l'État du Magnétisme Terrestre à Bruxelles pendant les douze années de 1827 à 1839. 4to. *Bruxelles* 1839.
- QUERARD (J. M.) Révue Bibliographique. Année. I. Nos. 1—4. 1839. The Editor.
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PRESENTS.

DONORS.

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- SCHOMBURGK (R. H.) Description of British Guiana, Geographical and Statistical. 8vo. *Lond.* 1840.
- SCHUMACHER (H. C.) *Astronomische Nachrichten.* Nos. 378-401. 4to. *Altona* 1839.
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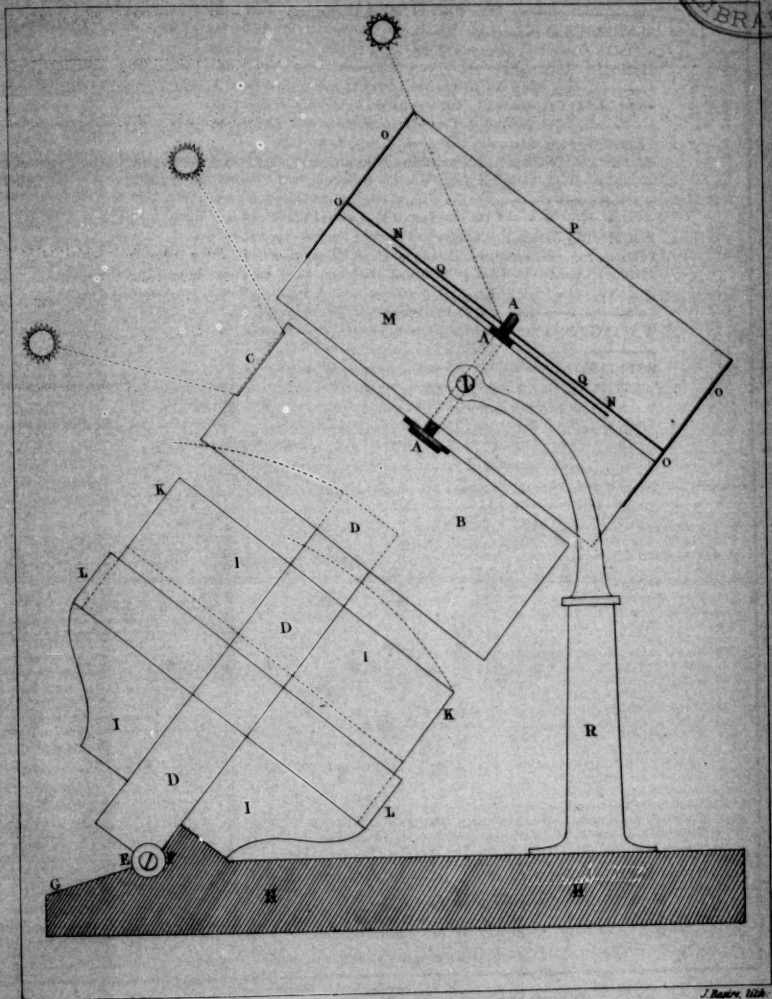
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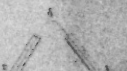
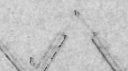
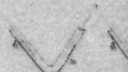
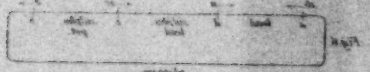
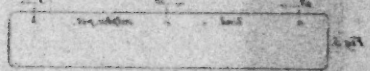
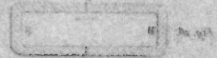
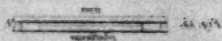
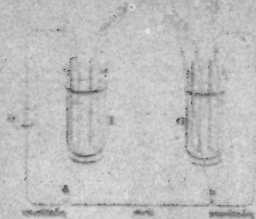
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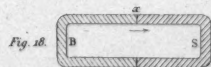
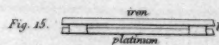
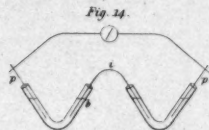
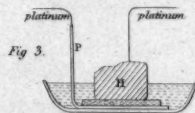
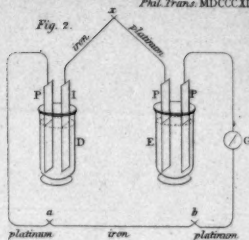
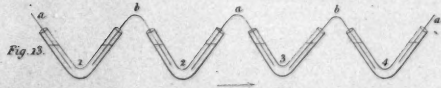
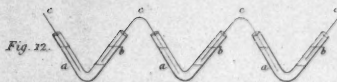
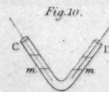
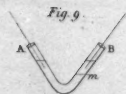
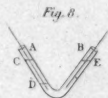
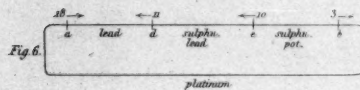
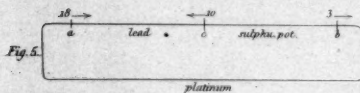
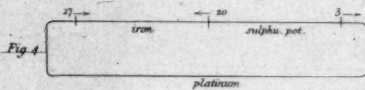
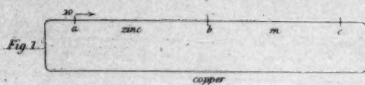
- ALBATEGNIUS MOHAM. De Numeris Stellarum et Motibus. 4to.
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- BURDACH (C. F.) Traité de Physiologie considérée comme Science d'Observation, avec des additions par Baer, Meyen, Müller, Meyer, Rathke, Valentin, Wagner. Traduit de l'Allemand par A. L. Jourdan. 8 Vols. 8vo. *Paris* 1837-38.
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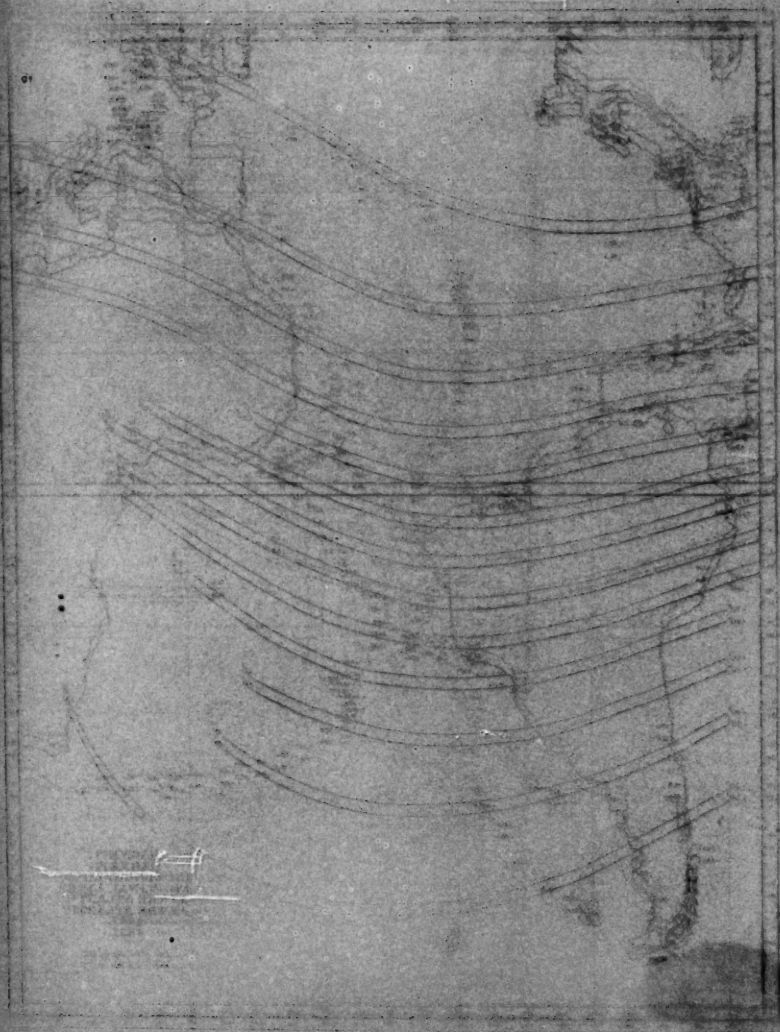
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- Nicholson's *Journal of Natural Philosophy, &c.* 5 Vols. 4to. *Lond.* 1797-1802.
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- KLUG et EHRENBURG. *Symbolæ Physicæ.* 2 Vols. folio. *Berlin* 1830.
- LAMARCK (J. B. P. A. de.) *Histoire Naturelle des Animaux sans Vertèbres.* 2^{me} édition. Révisé et augmenté par MM. G. P. Deshayes et H. Milne Edwards. 8 Vols. 8vo. *Paris* 1835-39.
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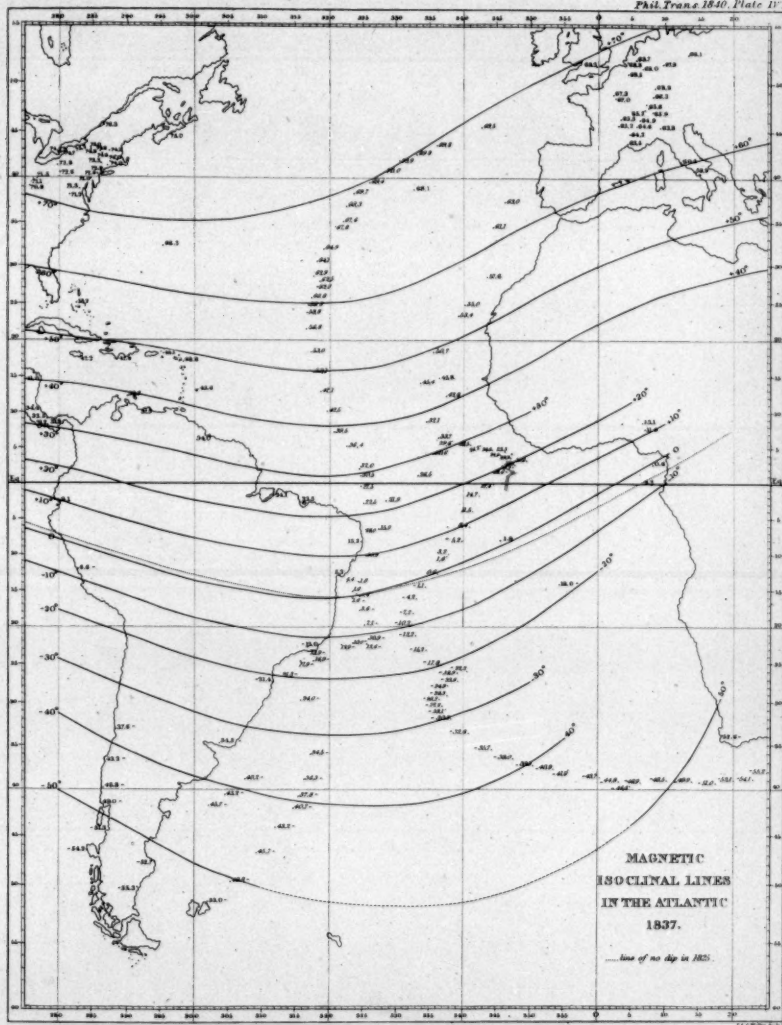
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- WAGNER (Rudolph.) Lehrbuch der Physiologie. Erste Abtheilung. 8vo. *Leipzig* 1839.
 Icones Physiologicæ. Folio. *Leipzig* 1839.
- WARING (Eduardus.) Meditationes Algebraicæ. 4to. *Cantabrigia* 1770.
 Meditationes Analyticæ. 4to. *Cantabrigia* 1776.
- WILLIAMS (Edward.) Theory and Practice of Gunnery. 8vo. *Lond.* 1766.
- WINTHER (M.) Literature Scientiæ rerum Naturalium in Dania, Norvegia et Holsatia usque ad Annum 1829, Enchiridion in usum Physicorum et Medicorum. 8vo. *Havniæ* 1829.
- YOUNG (J. R.) Elements of Plane and Spherical Trigonometry; to which is added some Original Researches in Spherical Geometry, by T. S. Davies, F.R.S.E., &c. 12mo. *Lond.* 1833.

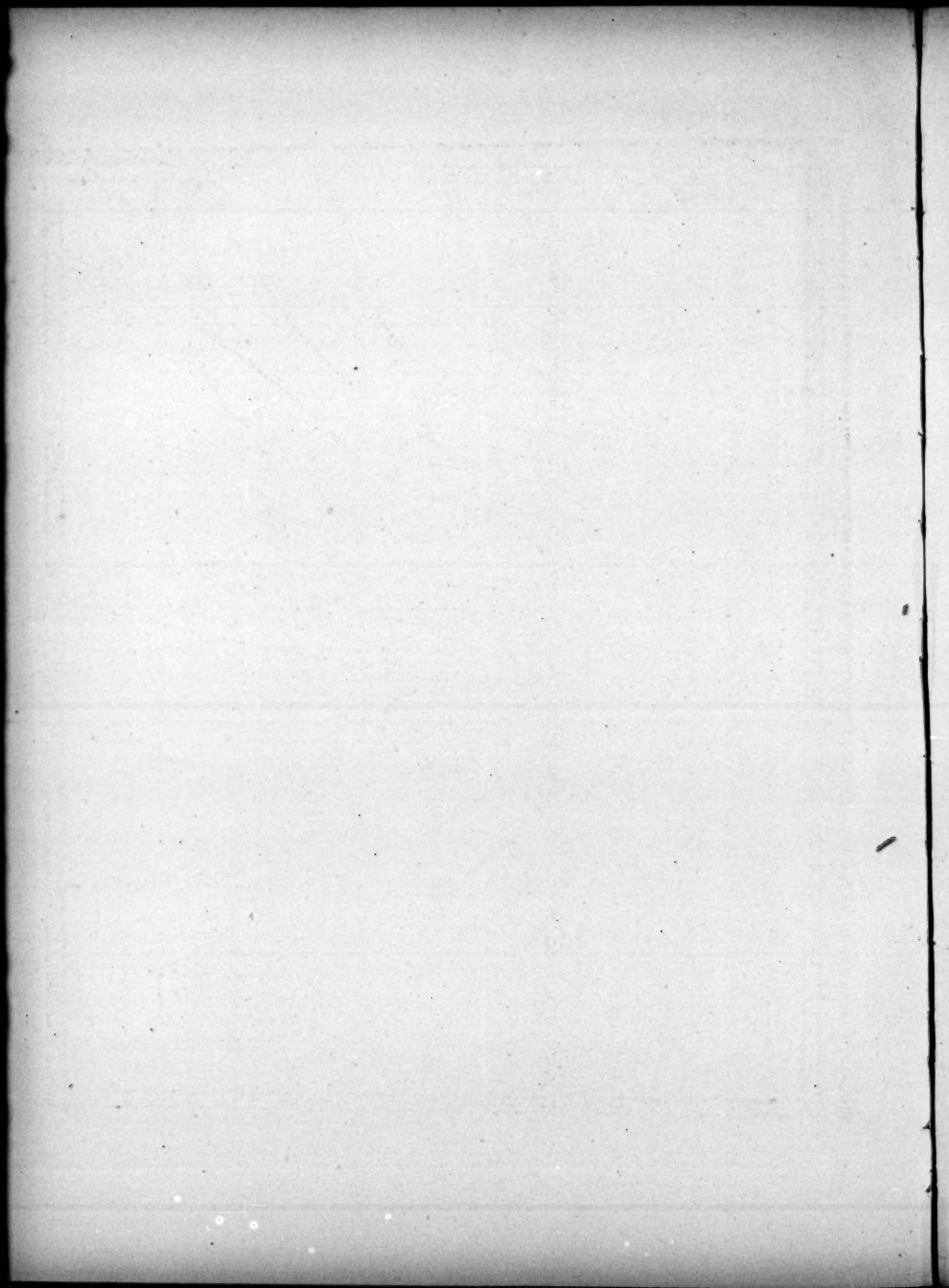


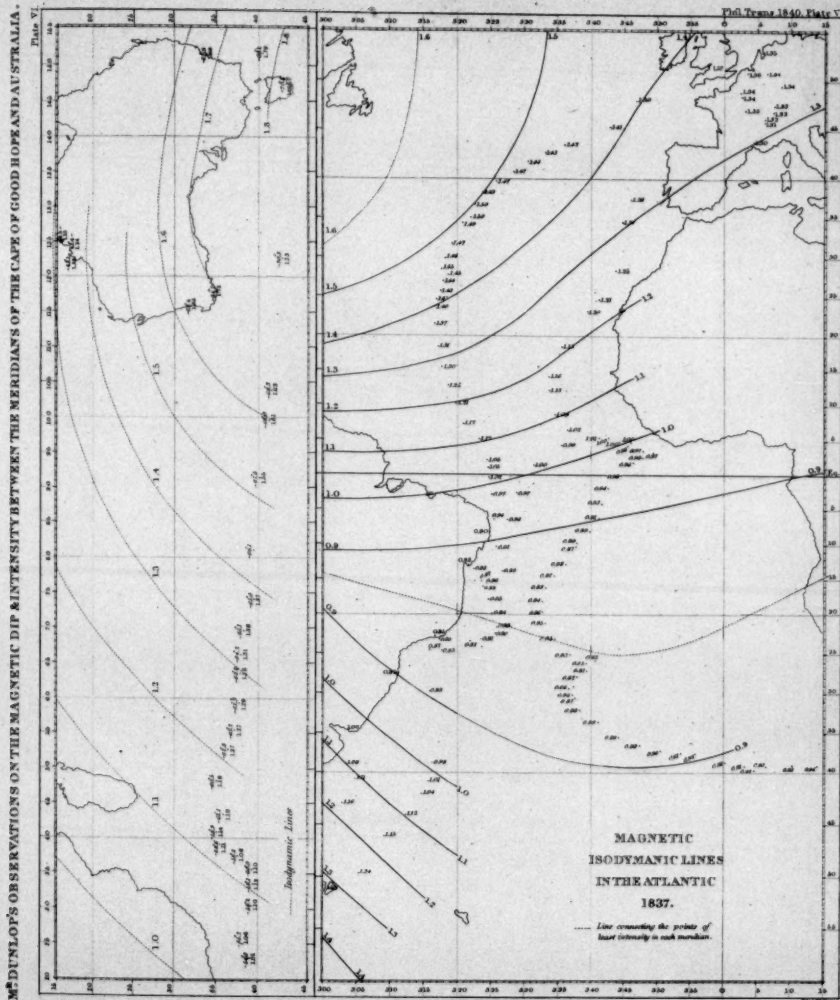


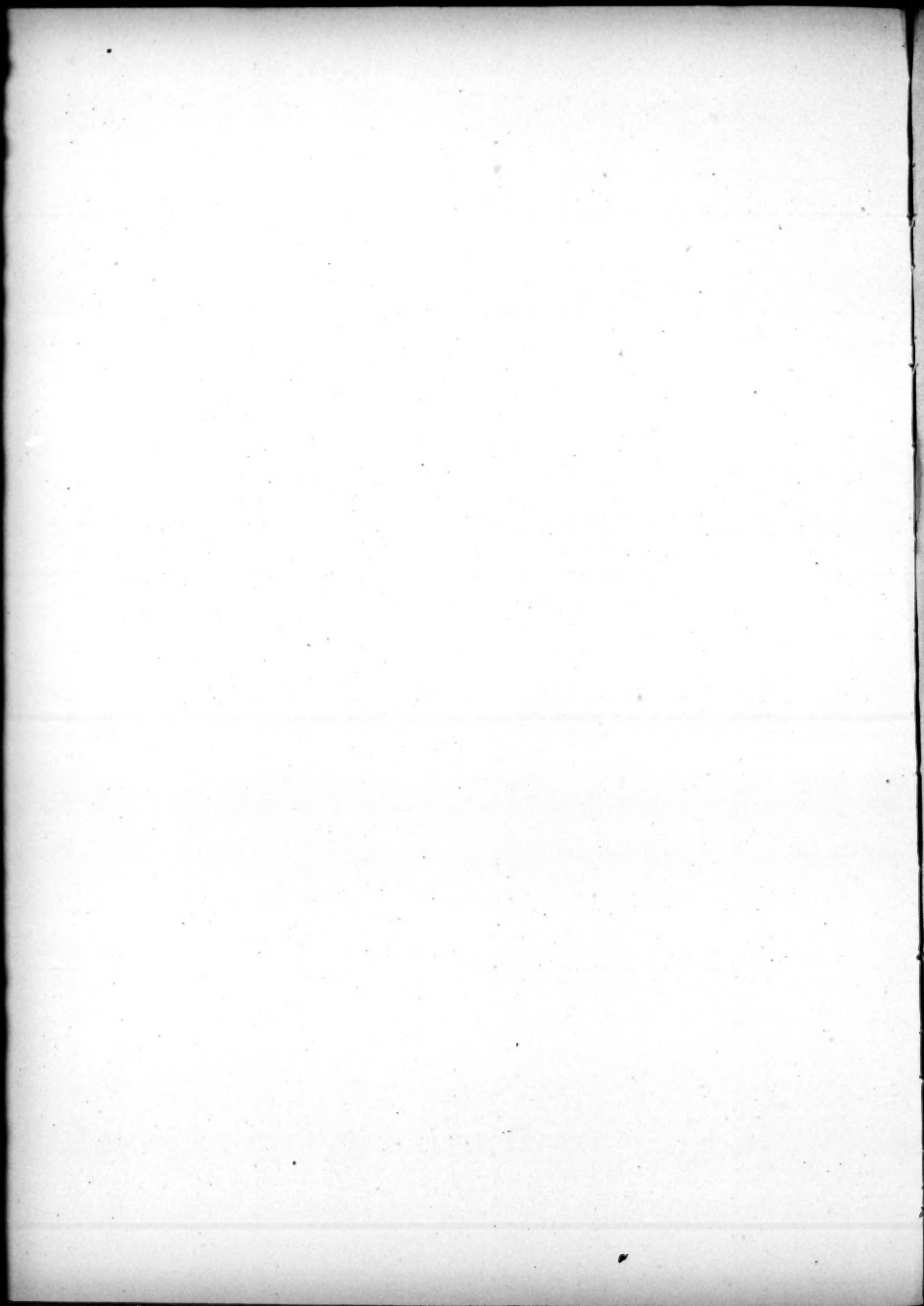












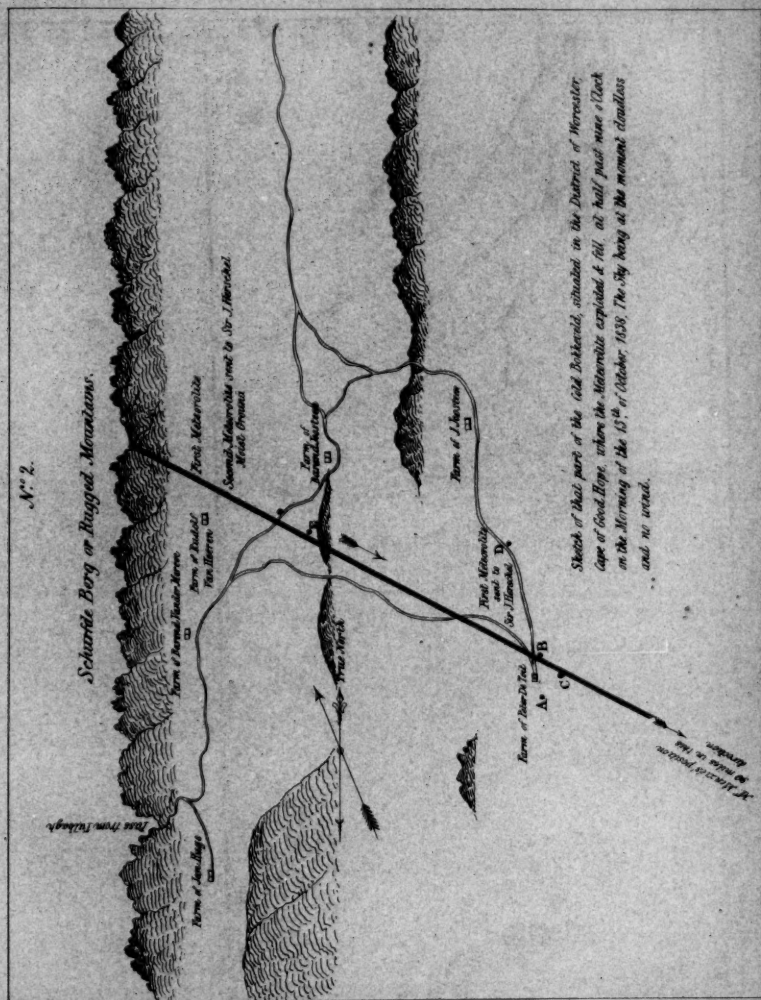


Figure 1.
Curve representing the values of $G(s) \cos \varphi(s)$

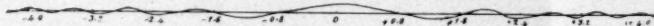
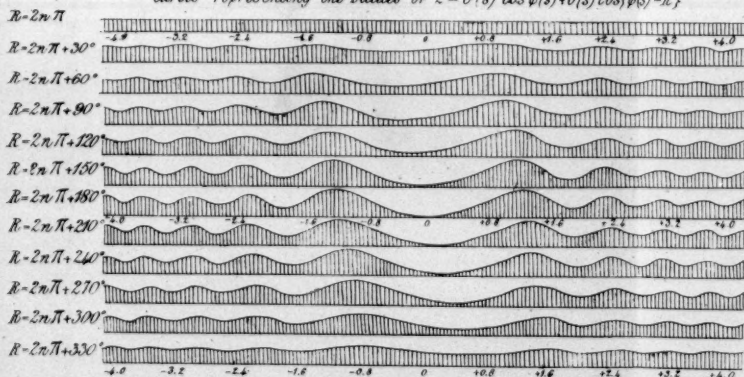


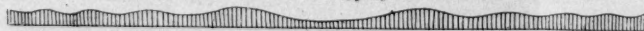
Figure 2.
Curve representing the values of $G(s) \cos \{\varphi(s) - 90^\circ\}$



Figure 3
Curves representing the values of $2 - G(s) \cos \varphi(s) + G(s) \cos \{\varphi(s) - 90^\circ\}$



Curve representing the $\frac{1}{2}$ part of the aggregate of all the values above



Curves
suppose
in the
the spec

$R=2n\pi$

$R=2n\pi+30^\circ$

$R=2n\pi+60^\circ$

$R=2n\pi+90^\circ$

$R=2n\pi+120^\circ$

$R=2n\pi+150^\circ$

$R=2n\pi+180^\circ$

$R=2n\pi+210^\circ$

$R=2n\pi+240^\circ$

$R=2n\pi+270^\circ$

$R=2n\pi+300^\circ$

$R=2n\pi+330^\circ$

Curves representing
change of 30° in R , at
end of the spectrum

$R=2n\pi$

$R=2n\pi+30^\circ$

$R=2n\pi+60^\circ$

$R=2n\pi+90^\circ$

$R=2n\pi+120^\circ$

$R=2n\pi+150^\circ$

$R=2n\pi+180^\circ$

$R=2n\pi+210^\circ$

$R=2n\pi+240^\circ$

$R=2n\pi+270^\circ$

$R=2n\pi+300^\circ$

$R=2n\pi+330^\circ$

Curve repr

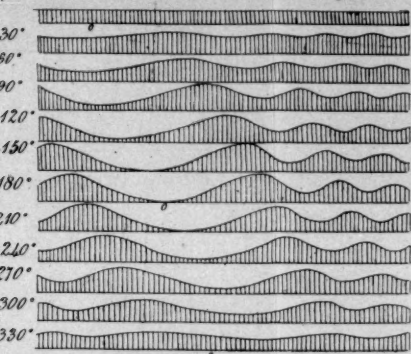
Curve repr

Curve repr

Curve repr

Figure 4.

es representing the values of $2-G(s)$ as $g(s)+G(s)$ as $g(s)$ in R ,
 using the origin of s shifted 0.15 for each change of 30° in R ,
 the direction corresponding to the case of the red end of
 spectrum on the same side as the retarding plate.

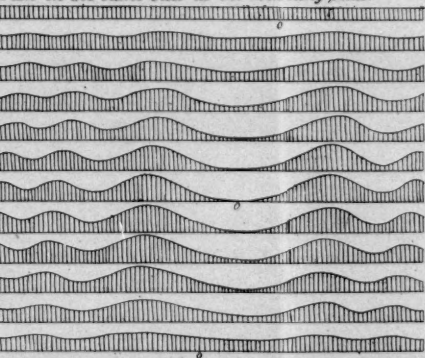


Curve representing $\frac{1}{4}$ part of the aggregate of the values above.

Curve representing $\frac{1}{4}$ part of the aggregate, supposing the number of curves increased to 24.

Figure 5.

ing the values, supposing the origin of s shifted 0.1 for each
 R , in the direction corresponding to the case of the violet
 spectrum on the same side as the retarding plate.

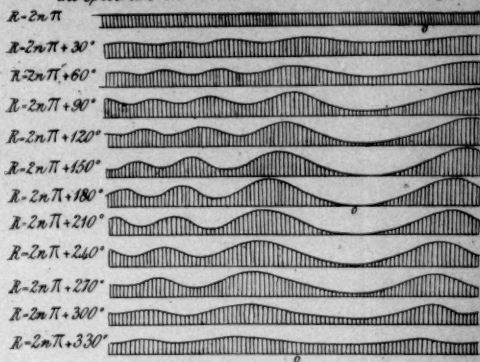


Curve representing $\frac{1}{4}$ part of the aggregate of the values above.

Curve representing $\frac{1}{4}$ part of the aggregate, supposing the number of curves increased to 24.

Figure 6.

Curves representing the values, supposing the origin
 of s shifted 0.15 for each change of 30° in R , in the
 direction corresponding to the case of the violet end of
 the spectrum on the same side as the retarding plate.

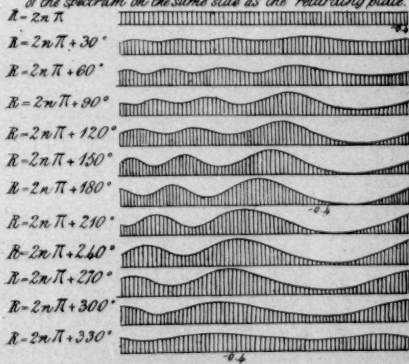


Curve representing $\frac{1}{4}$ part of the aggregate of the values above.

Curve representing $\frac{1}{4}$ part of the aggregate, supposing the number of curves increased to 24.

Figure 7.

Curves representing the values, supposing the origin
 of s shifted 0.2 for each change of 30° in R , in the
 direction corresponding to the case of the violet end
 of the spectrum on the same side as the retarding plate.



Curve representing $\frac{1}{4}$ part of the aggregate of the values above.

Curve representing $\frac{1}{4}$ part of the aggregate, supposing the number of curves increased to 24.



FIG. 1. The structure of the plant, showing the roots and the stem.

FIG. 2. The structure of the plant, showing the roots and the stem.

FIG. 3. The structure of the plant, showing the roots and the stem.



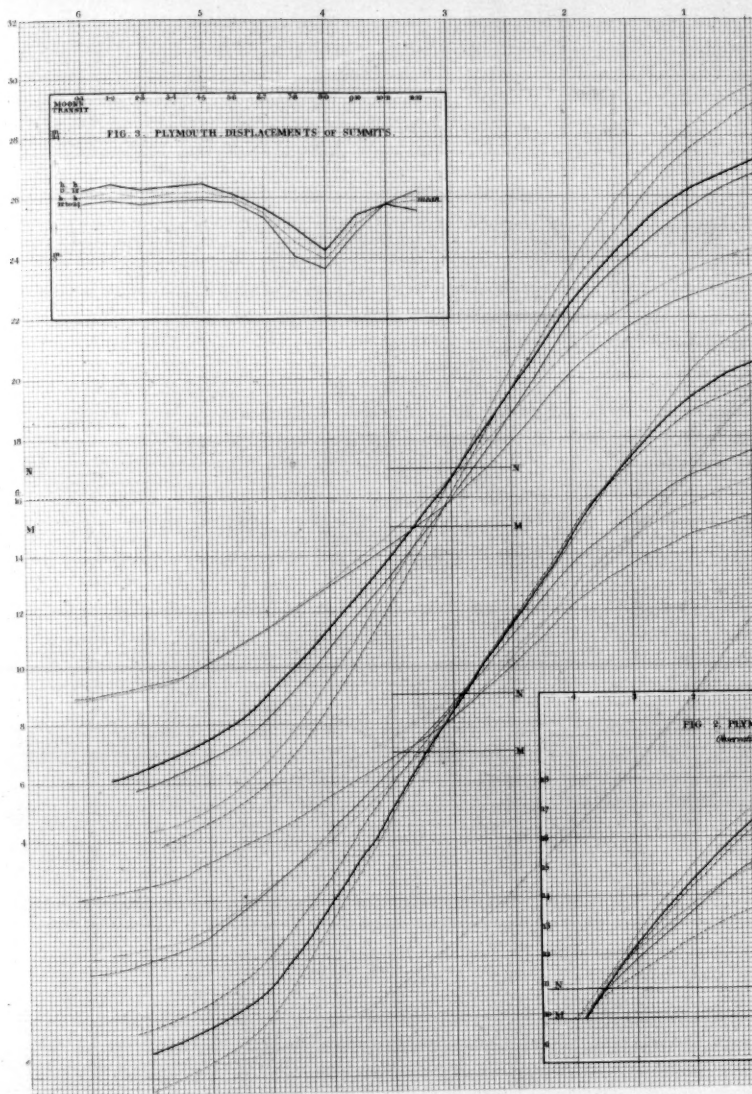
Disease of the Spinal Nerves.

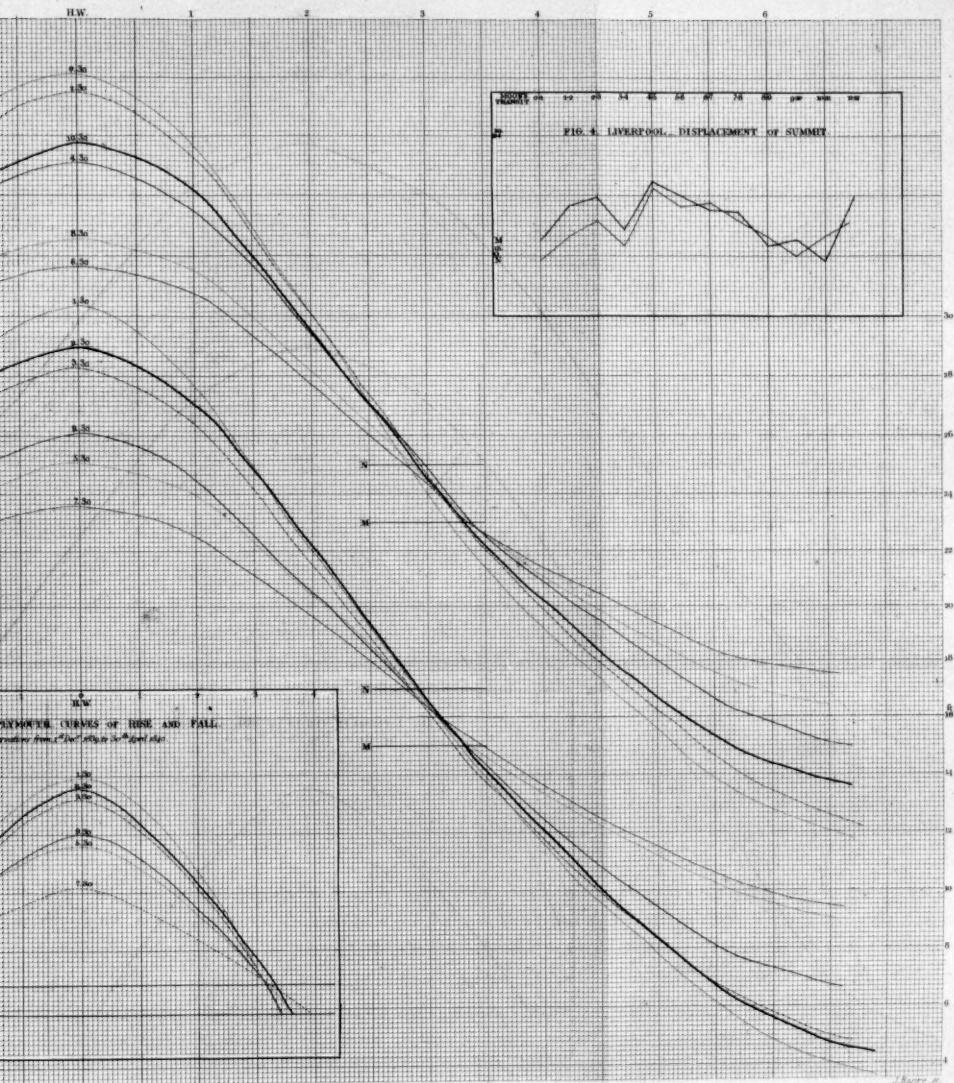
A.A. The Spinal marrow divided from behind.

B.B. The tumour on the anterior roots, divided.

C.C.C.C. The Posterior roots of the nerves passing the tumour & free.

FIG. 1. — LIVERPOOL. — CURVES OF RISE





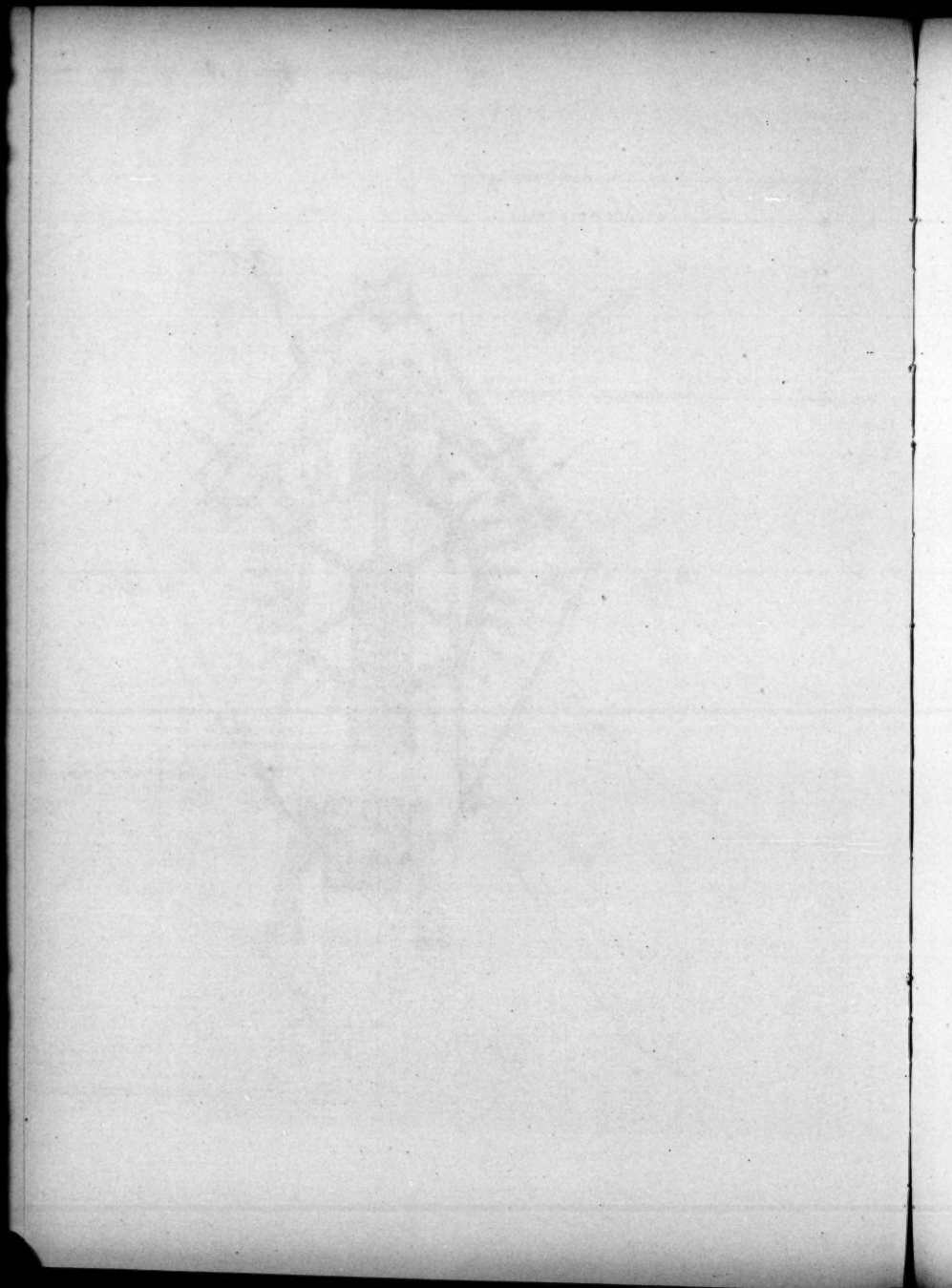
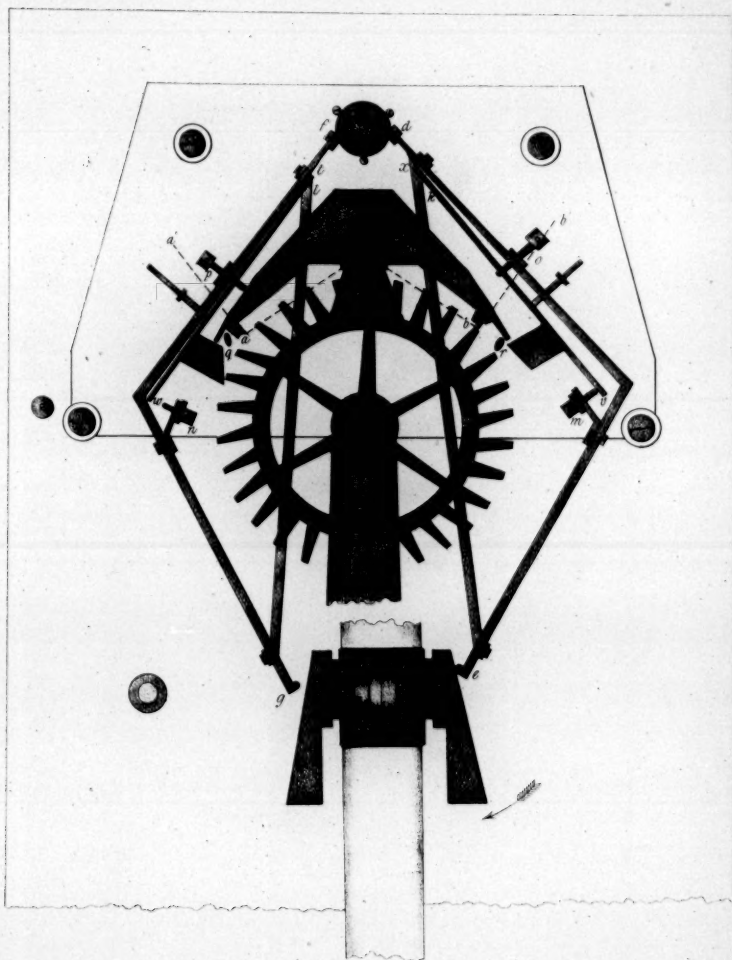


Fig. 1.



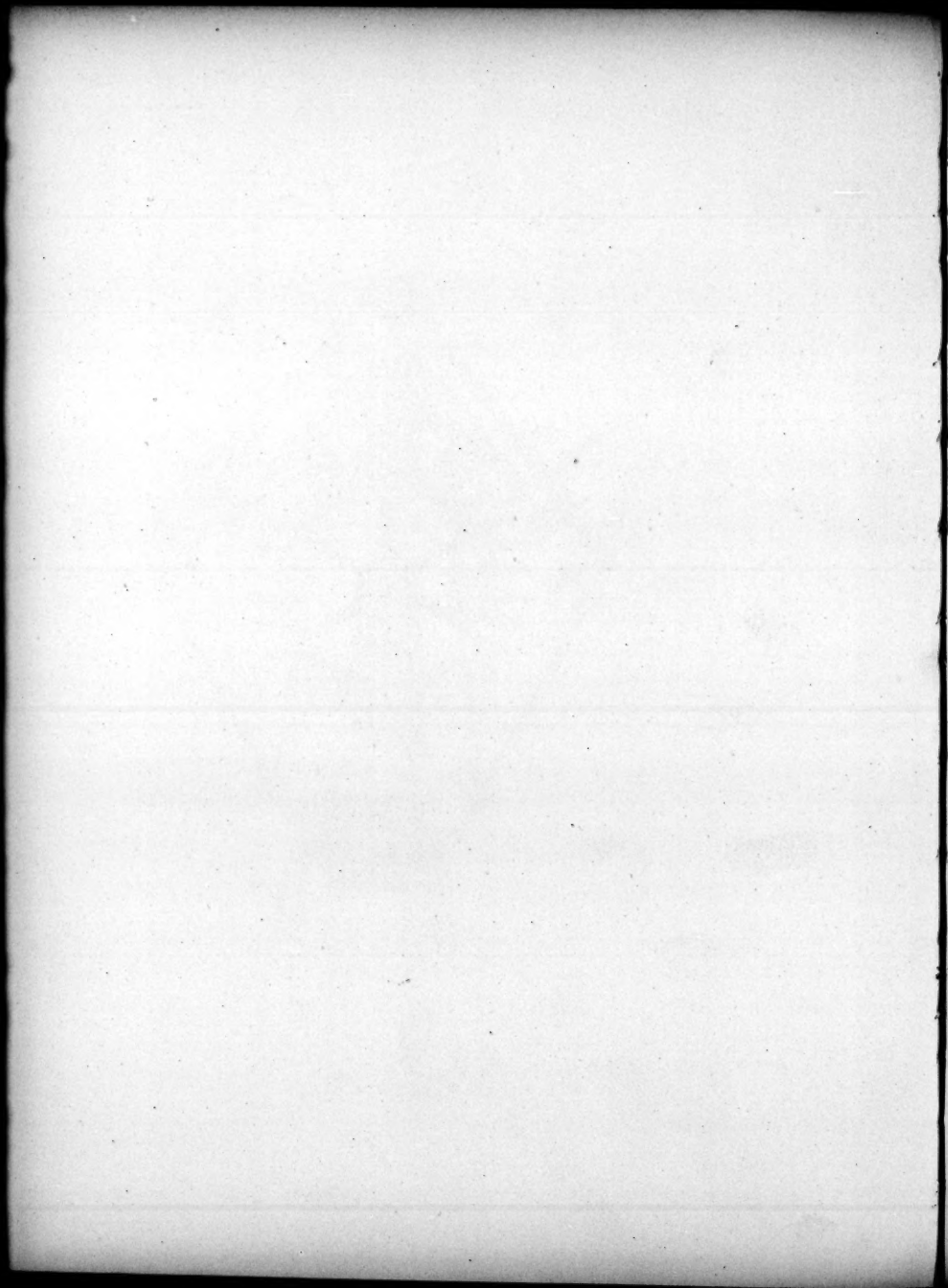


Fig. 2.



Fig. 4.

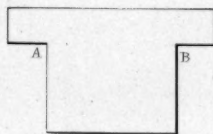
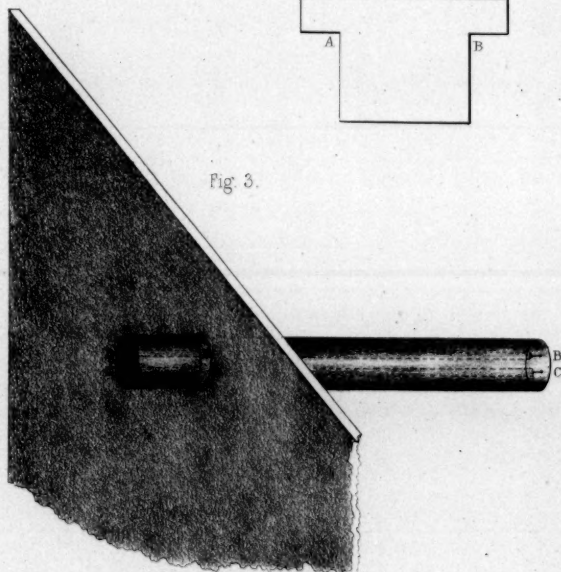
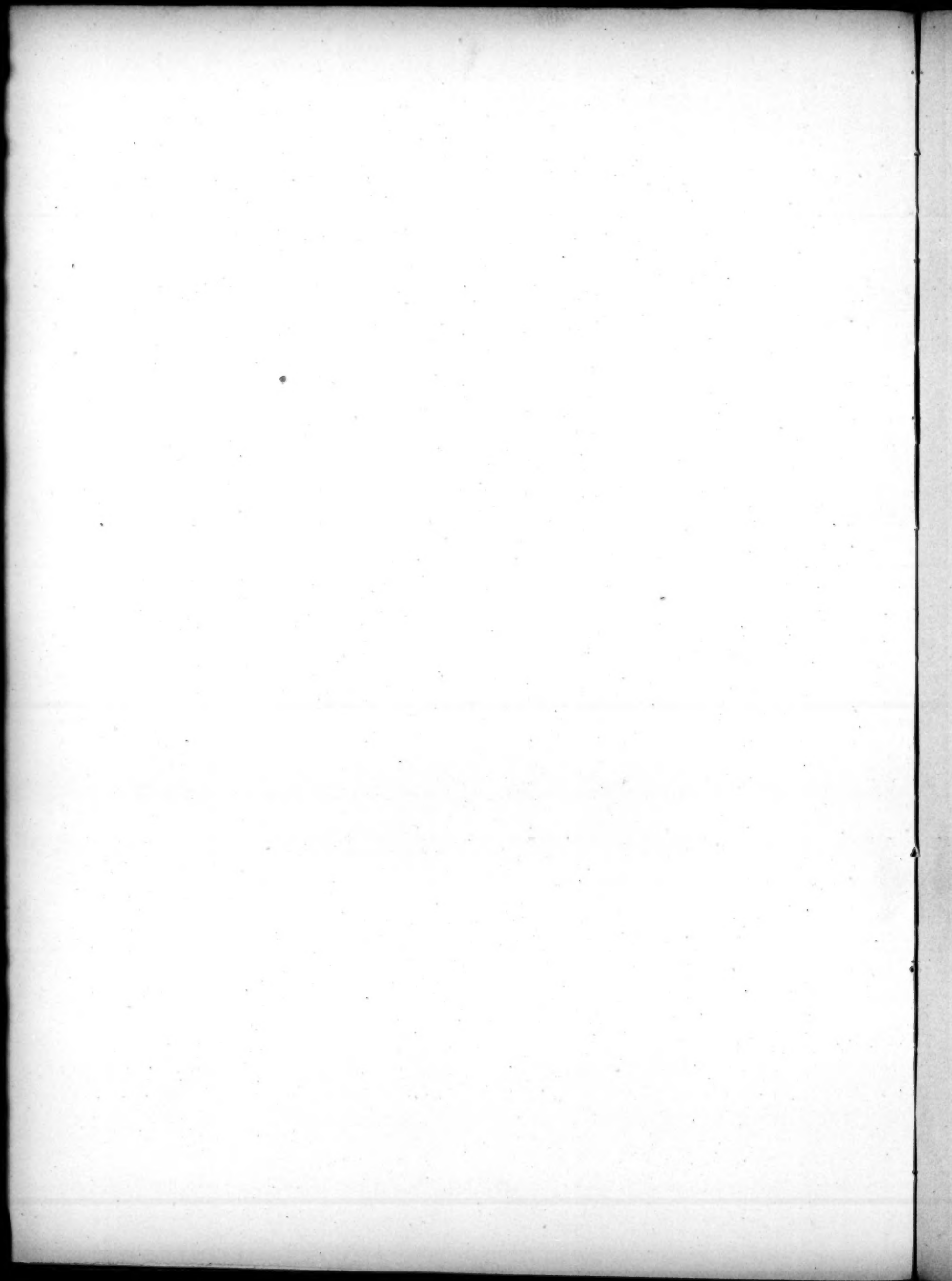
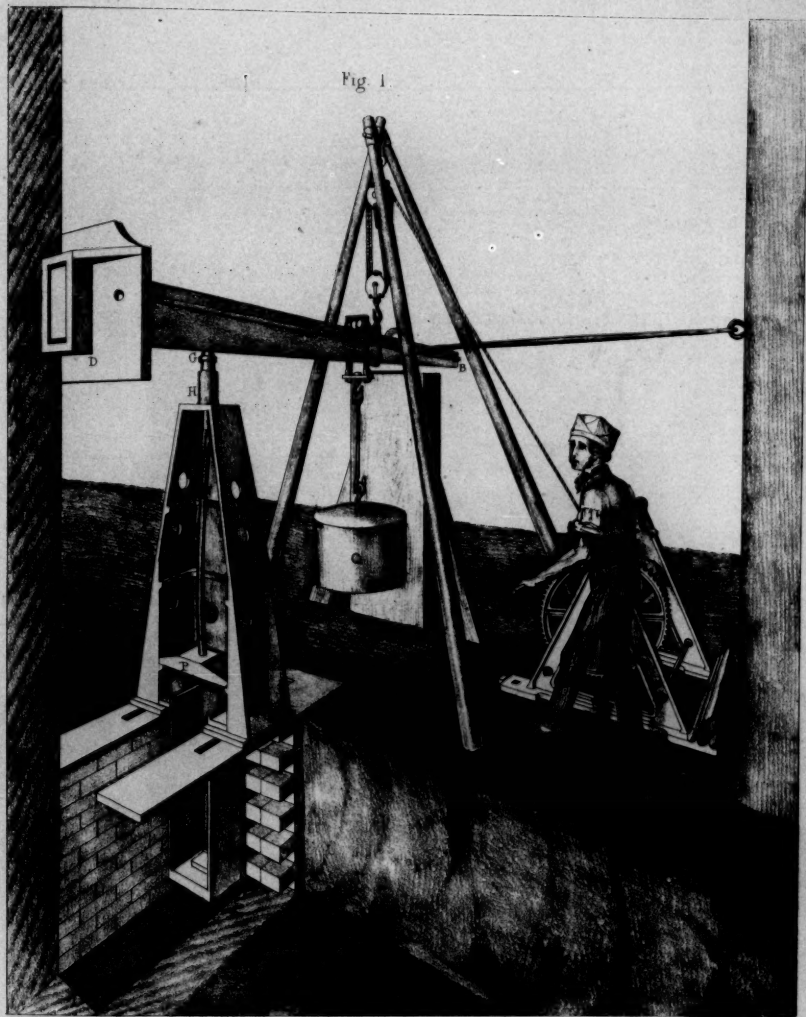


Fig. 3.







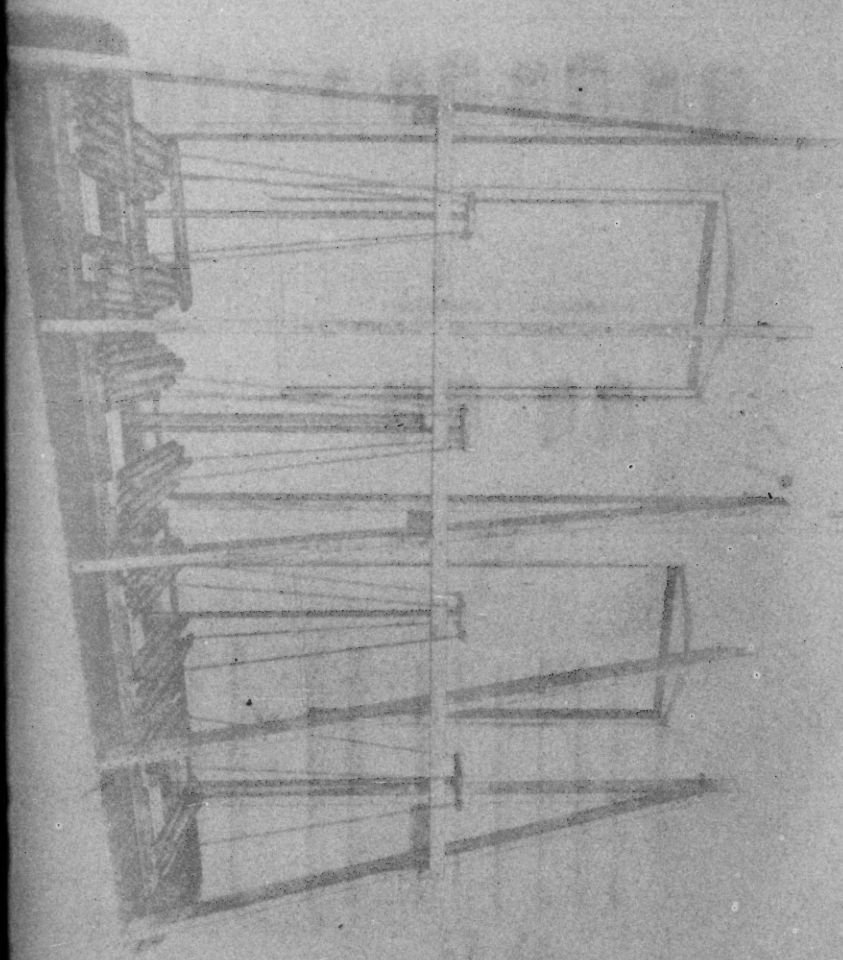
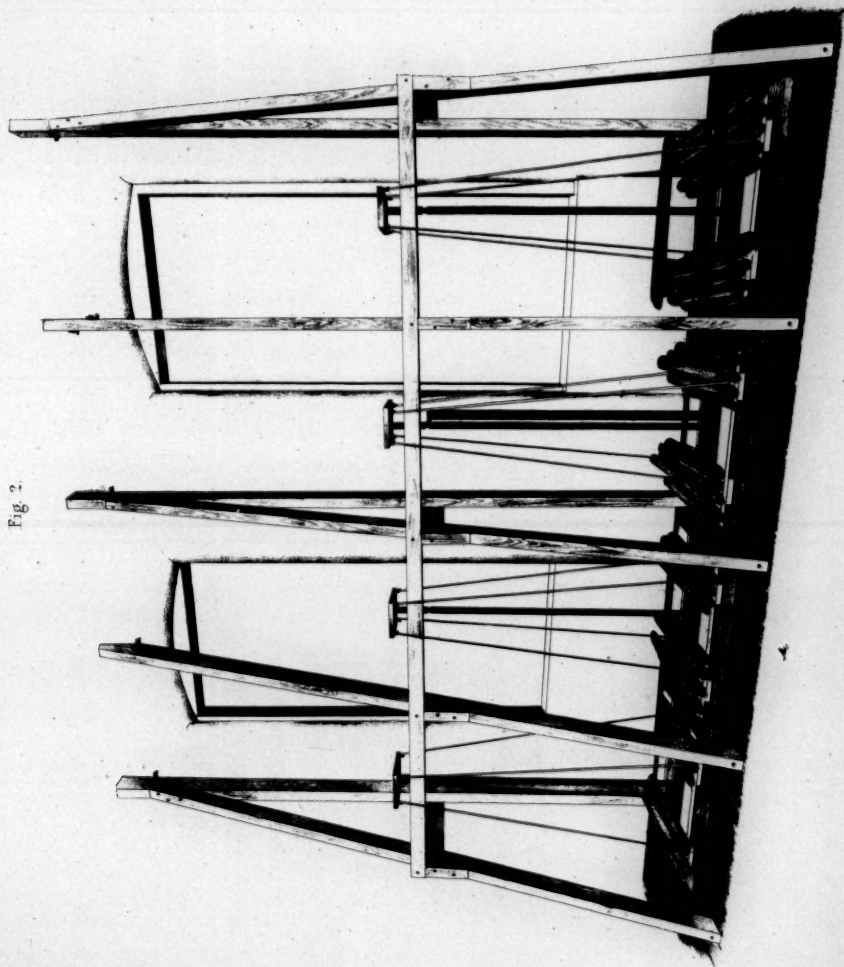
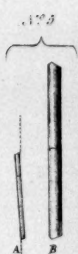
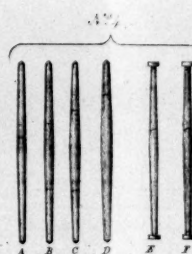
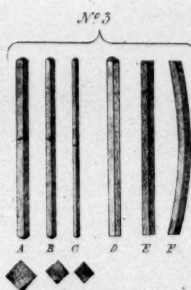
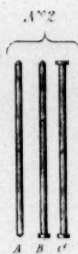
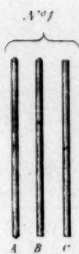
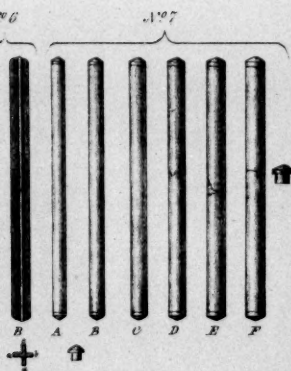
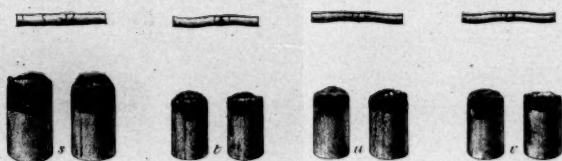
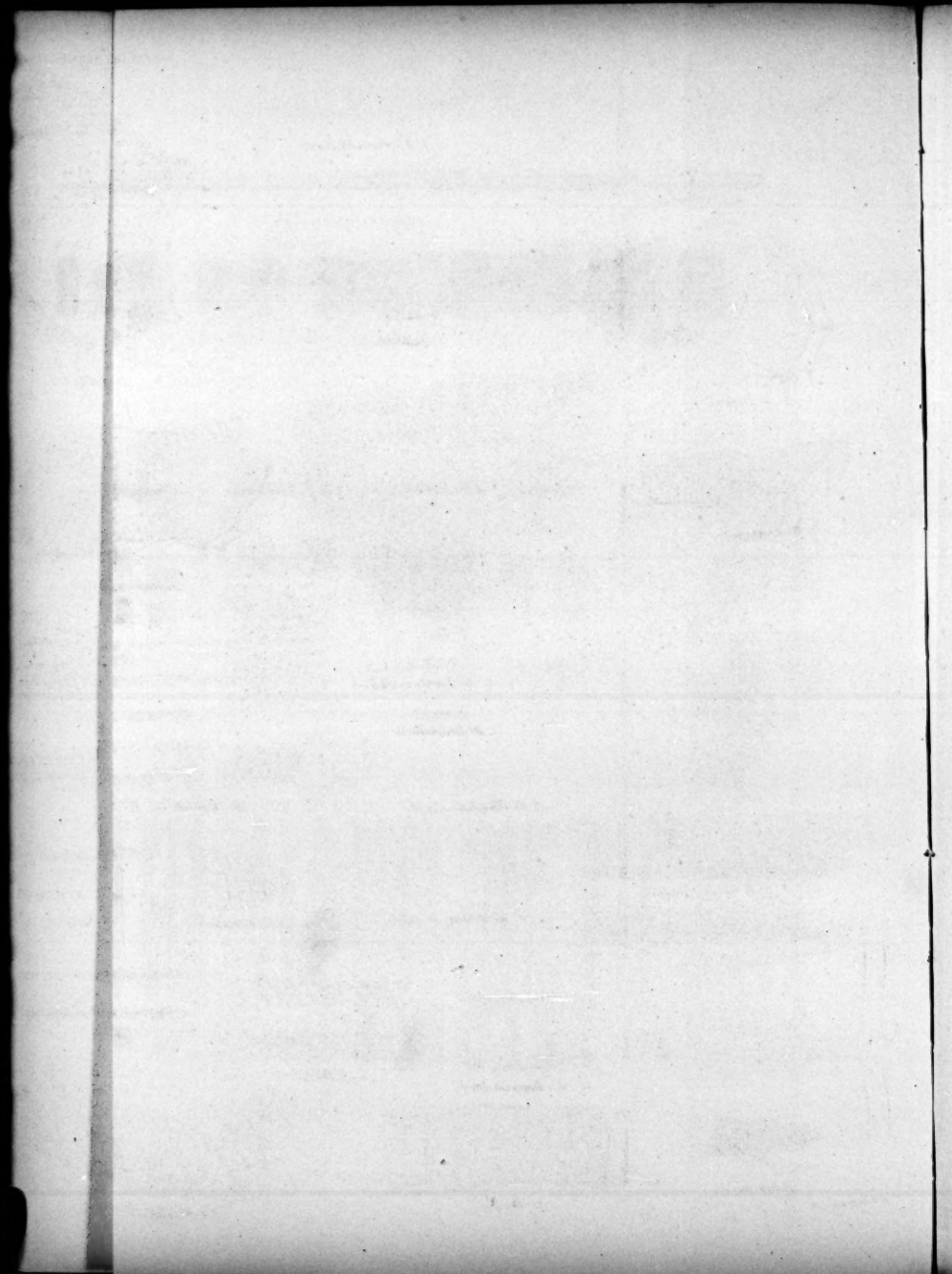


Fig. 2.







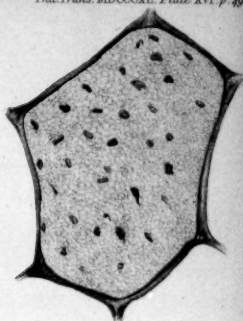




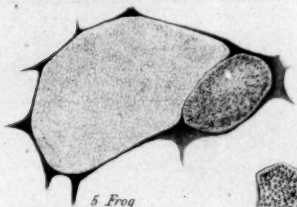
1 Human



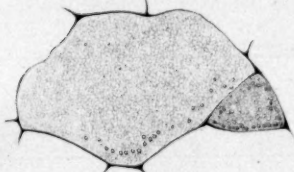
2 Staghorn Beetle



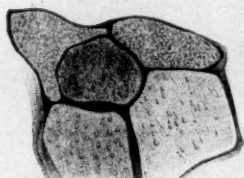
3 Skate



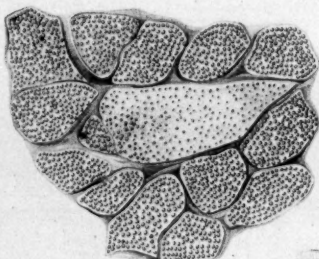
5 Frog



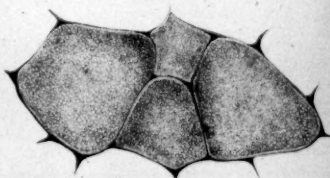
4 Haddock



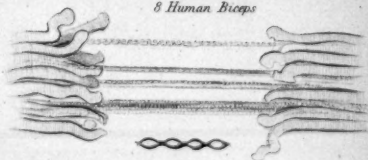
6 Boa



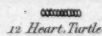
7 Teal



8 Human Biceps



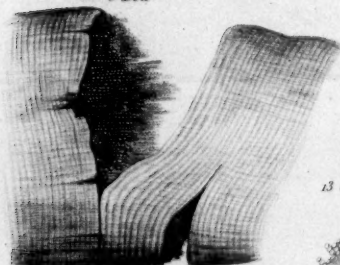
11 Rectus Oculi, Fish



12 Heart, Turtle



13 Esophagus, Turtle



9 Boa, 400 Diam.



16 Rabbit at Birth



14 Chameleon



15 Hare



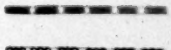
10 Rabbit at Birth



20 Staghorn Beetle



19 Duck



18 Crab



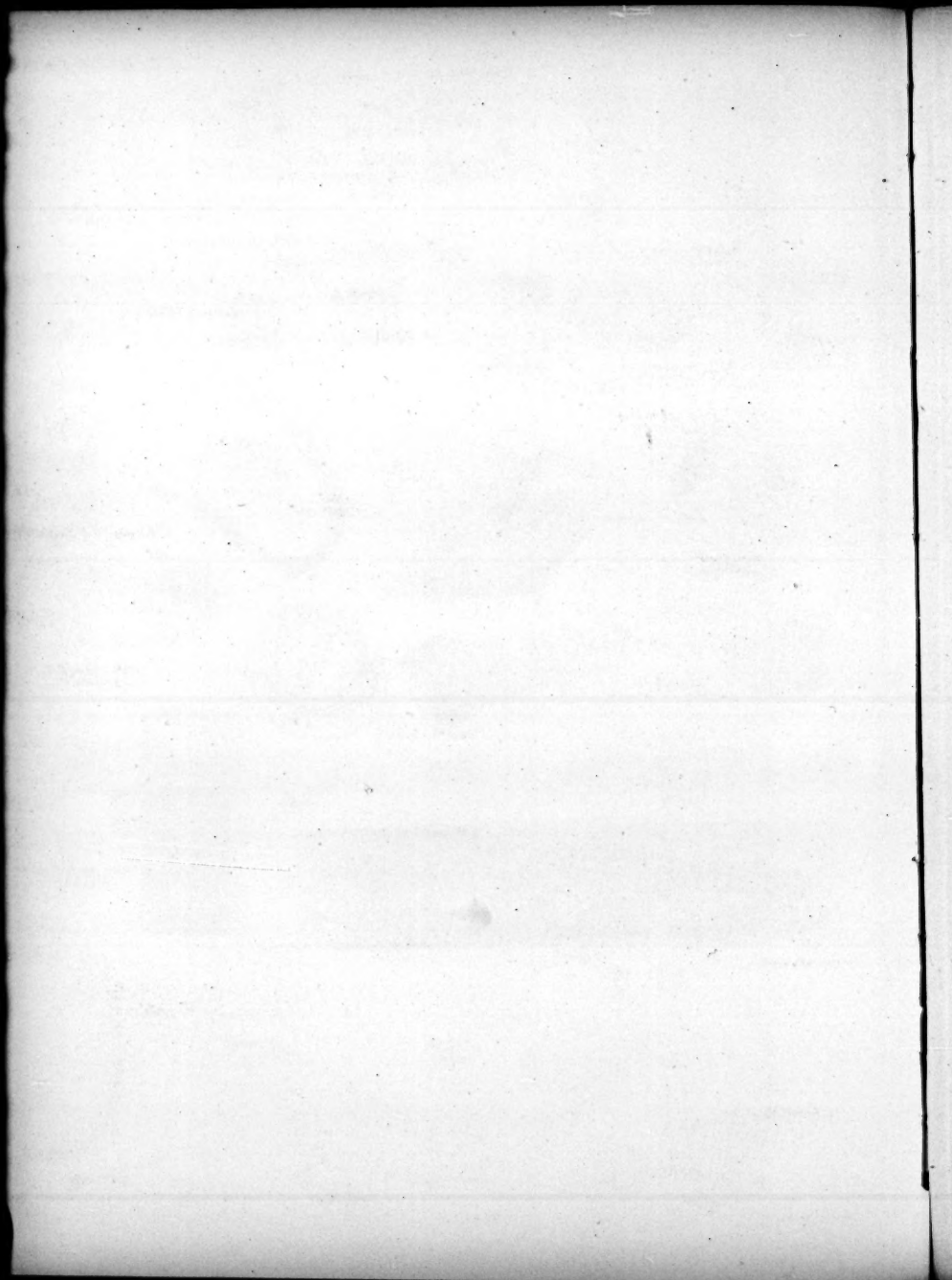
17 Heart, Cat



21 Pig

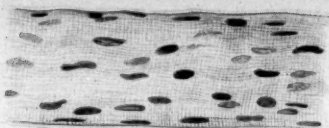


22 Human





46 Land Lizard
Citric Acid.



48 Frog.



50 Human
Phosph. Acid.



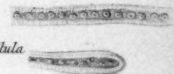
47 Land Lizard
Citric Acid.



49 Frog.

53

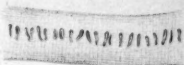
Larva Libellula



51 Horse
Tartaric Acid.



52 Pig.
Tartaric Acid.



54 Tipula.
Citric Acid.



55 Chrysalis of Tiger Moth.



56 Chick
10th day of Incubation.



58 Kitten at Birth
Tart. Acid.



60 Fetal Calf
of 2 months.



61 Human Fetus
9 months.

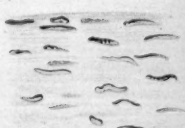


57 Kitten at Birth.

59



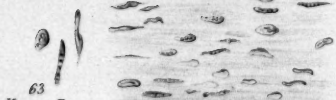
66 Human Stomach.



67 Stomach of Sheep
Tart. Acid.



65 Human Stomach
Tart. Acid.

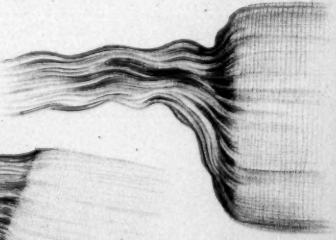


63 Human Fetus

62 Human Fetus
9 mo. Tart. Acid.



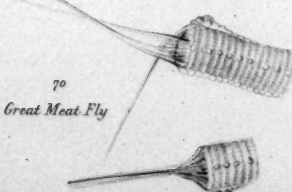
64 Child
2 years



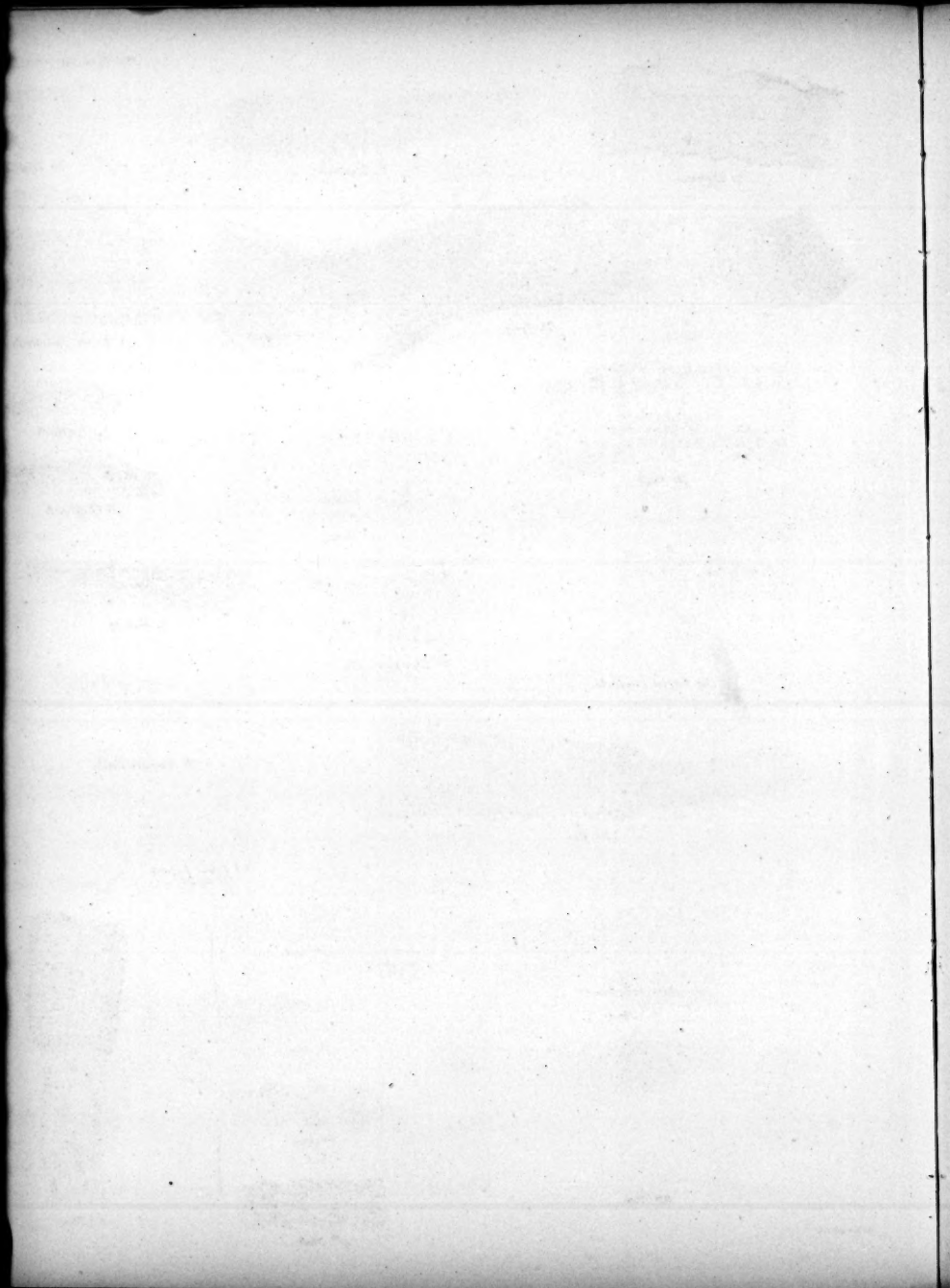
68 Skate

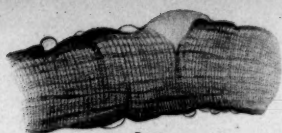


69 Skate



70
Great Meat Fly





71 *Dytiscus*.



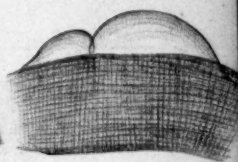
72 *Dytiscus*.



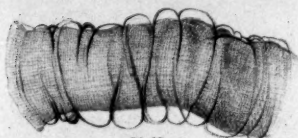
73 *Tipula*.



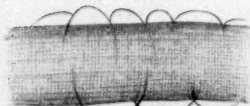
75 *Frog*.



74 *Larva Libellula*.



76 *Newt*.



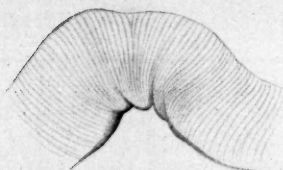
80 *Mouse*.



77 *Chaffinch*.



78 *Chaffinch*.



81 *Larva Libellula*.



82 *Blue Bottle Fly*.



79 *Human*.



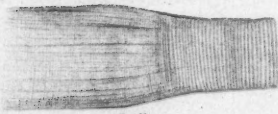
86 *Eel*.



83 *Staghorn Beetle*.



84 *Land Lizard*
(in Sculp)



87 *Skate*.



1st State.



2nd State.



3rd State.

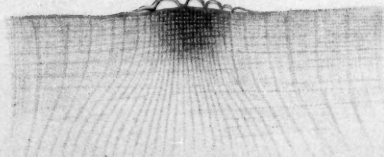


4th State.

88
Skate.



85 *Frog*.



89 *Grab*.

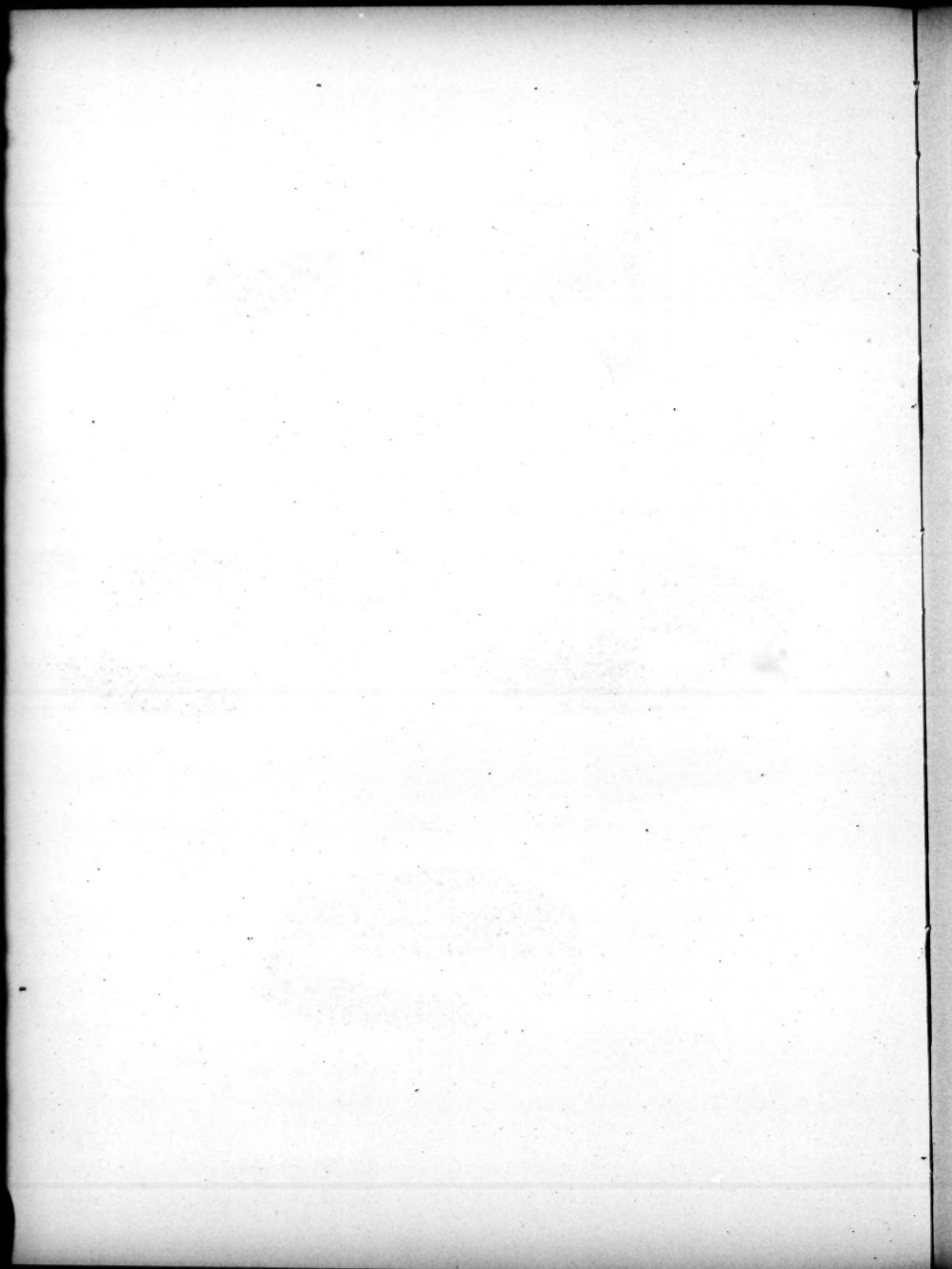


Fig. 1.

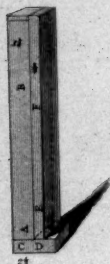


Fig. 2.

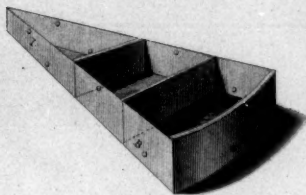


Fig. 3.

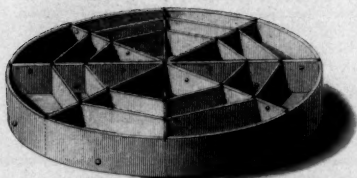


Fig. 4.

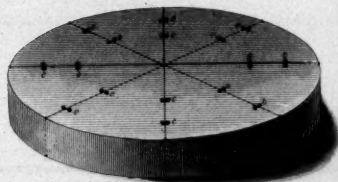


Fig. 5.

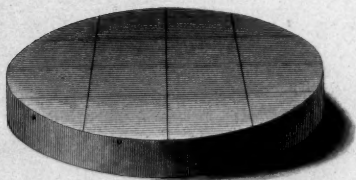




Fig. 7.



Fig. 6.

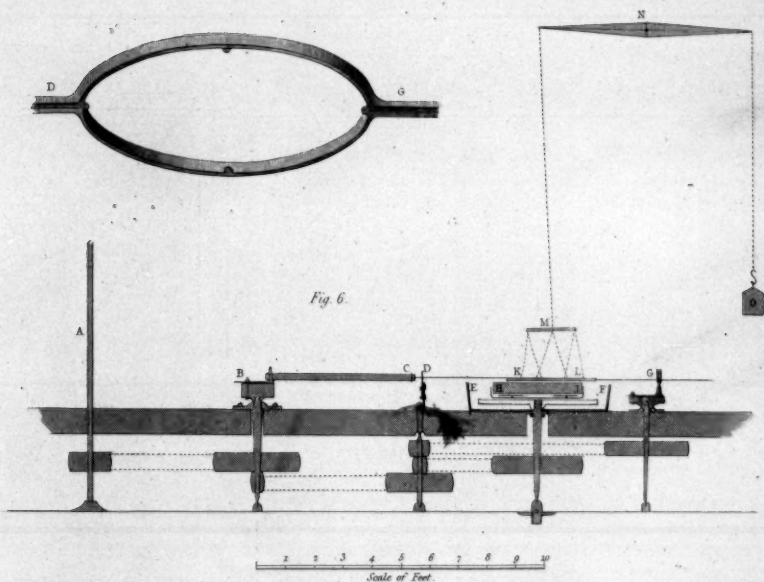


Fig. 8.

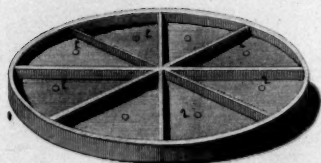
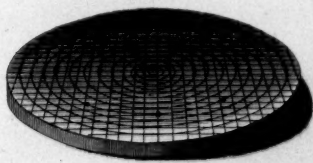
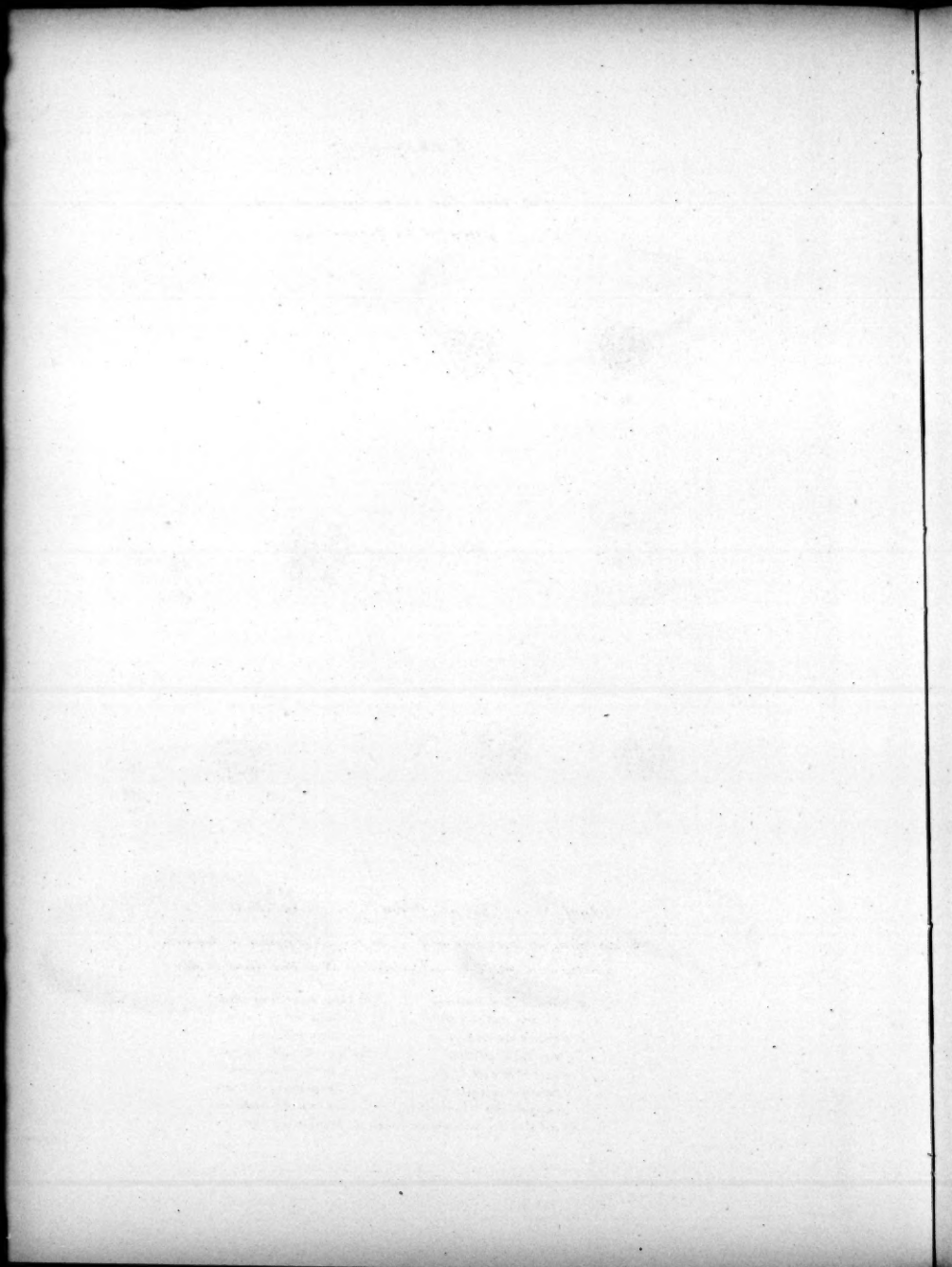


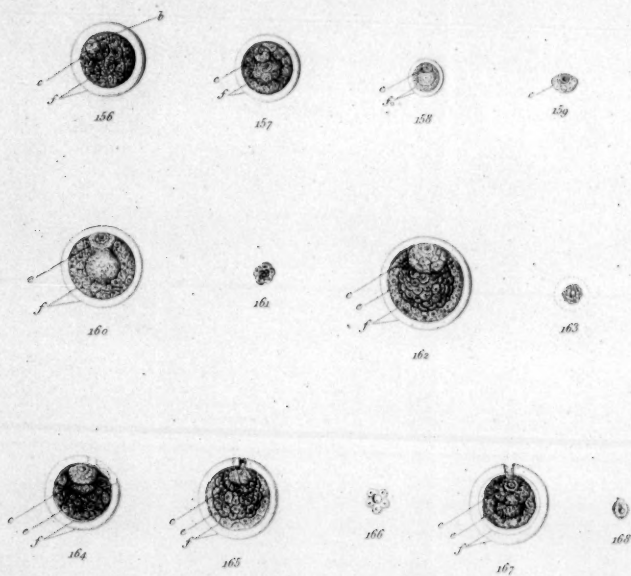
Fig. 9.





Embryology.

Ova from the Ovary, more or less
prepared for Fecundation.

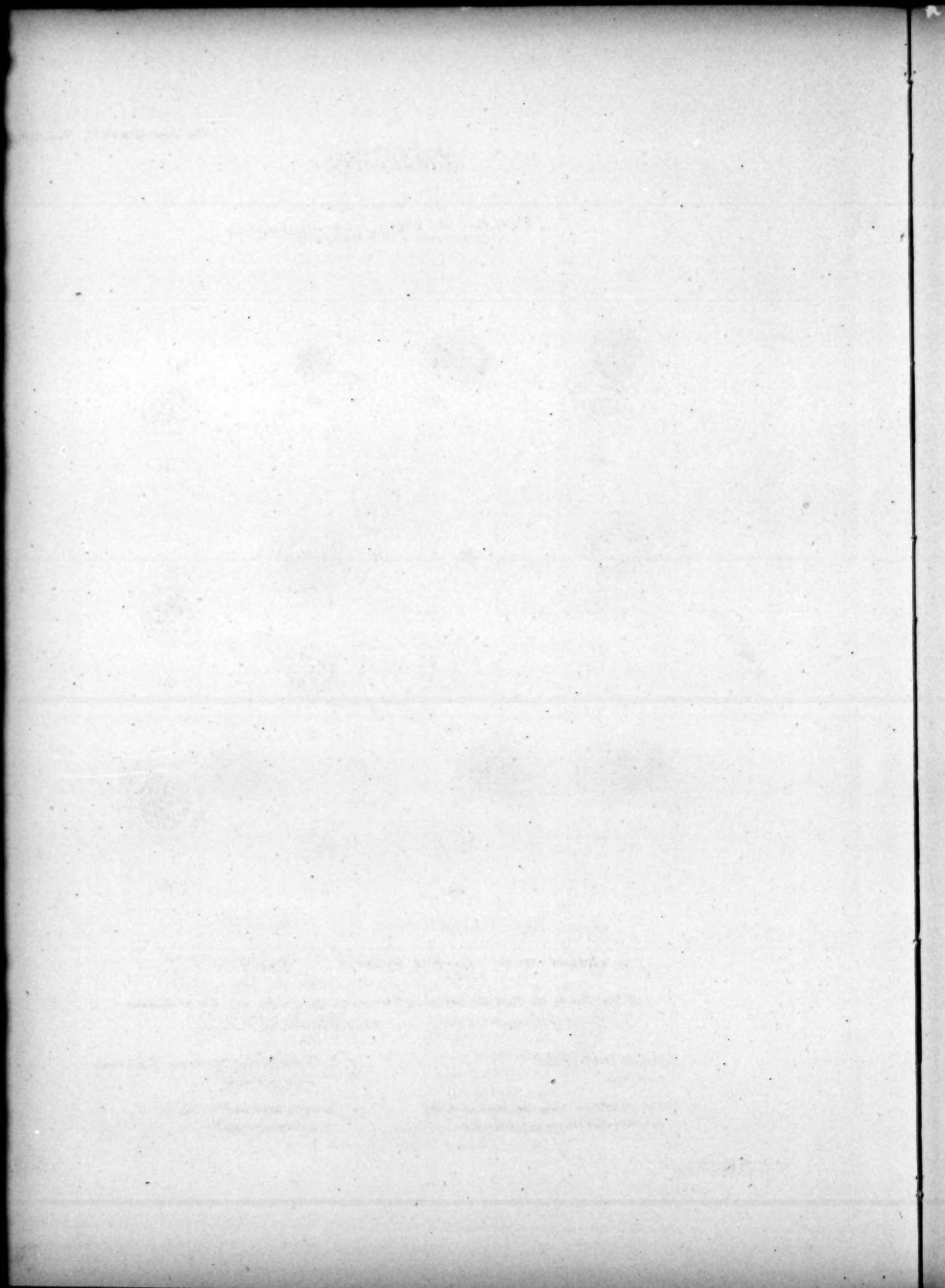


Actual Sizes. Largest Ovum (156) Smallest (168)

(All the Objects are from the Rabbit: — in Fig 158 magnified 50 diameters;
in Figures 161, 163, 166, 169, mag^d 300 diam.; in all the other Figures, 100 diam.)

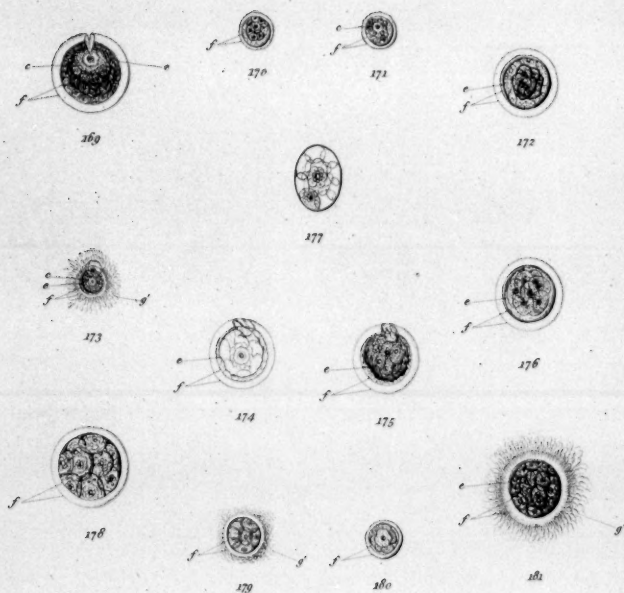
b Germinal Spot, beginning
to resolve itself into Cells.
c Germinal Vesicle, more or
less filled with Cells.
e Proper Membrane of the
Substance by which the
Germinal Vesicle is surrounded.

f Thick transparent Mem-
brane of the Ovum —
'Zona pellucida'
Fig^s 161, 163, 166, Central
Portion of the altered
Germinal Spot, its Centre
the Point of Fecundation.
Fig 168. Part of a Spermatozoon (!) seen in the Orifice Fig 167.



Embryology.

Ova from the Ovary, after Fecundation.



Actual Sizes; Largest Ovum (·) Smallest (·)

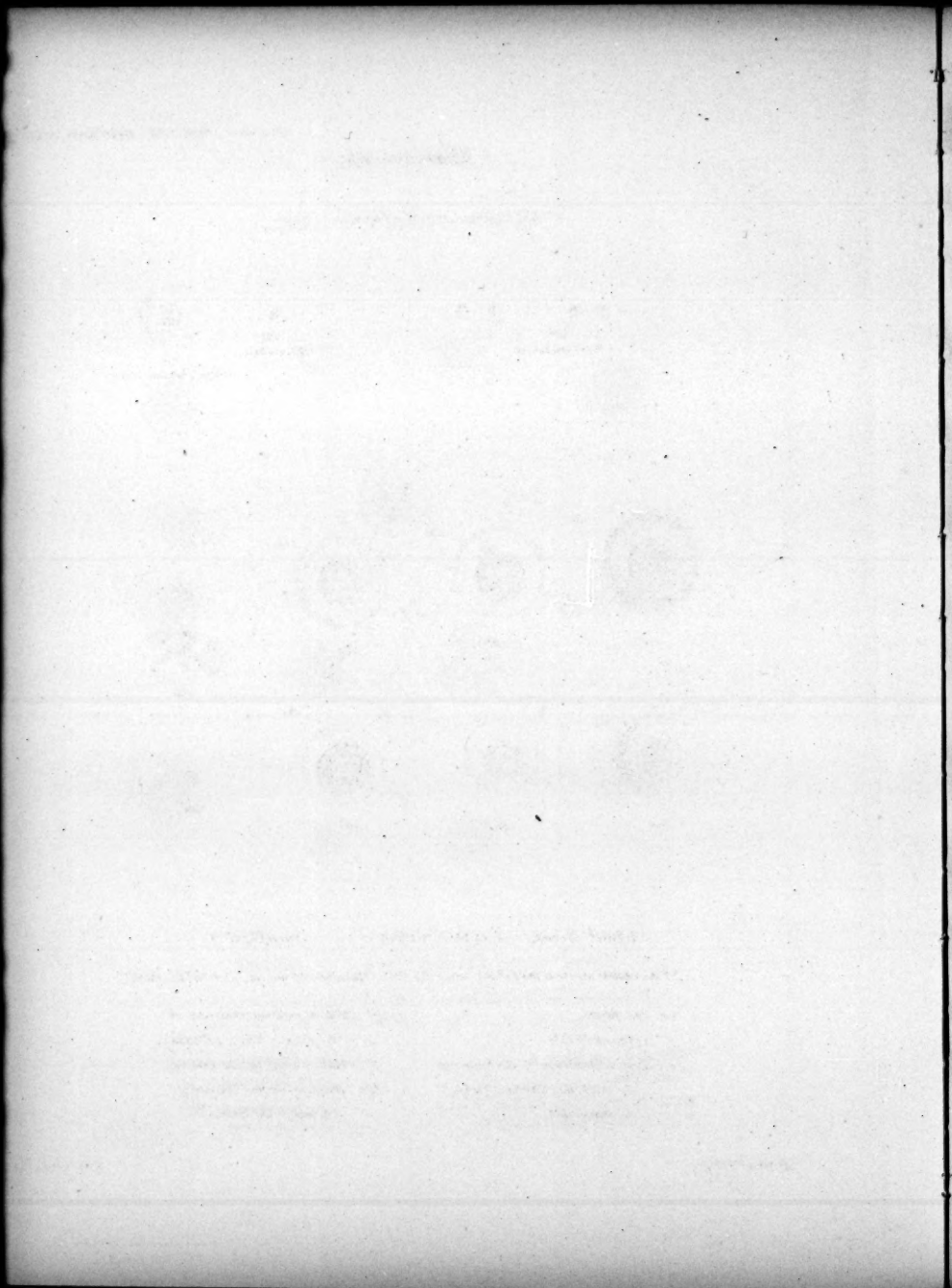
*(All the Objects are from the Rabbit; in Fig^s 170, 171, 173, 179, 180, magnified 50 Diameters;
in Fig. 177, mag^d 300 Diam.; in all the other Figures, 100 Diameters.)*

e Germinal Vesicle, filled
with Cells.

e Proper Membrane of the Substance by which
the Germinal Vesicle is surrounded.

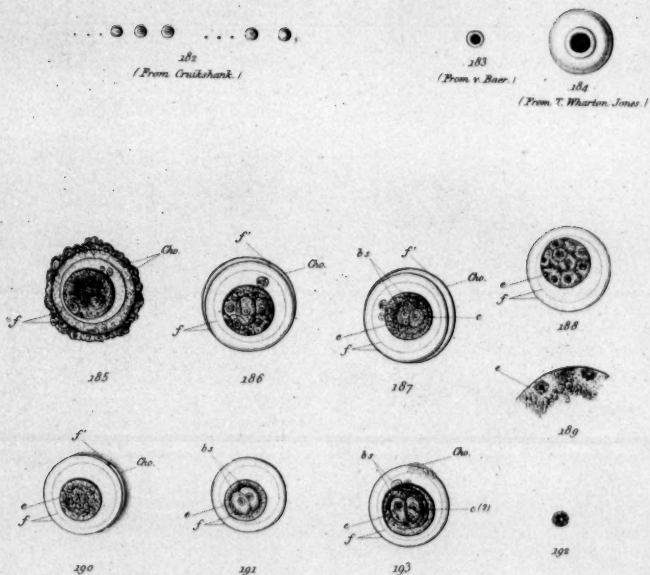
f Thick transparent Membrane of the Ovum.
"Zona pellucida"

g Tunica granulosa; its Cells in
an altered state.



Embryology.

Ova from the Fallopian Tube.



Actual Sizes; Largest Ovum (· · ·) Smallest (· · ·)

All the Objects are from the Rabbit, except Fig 183. — Fig^s 185 to 188, 190, 191, 193, mag^d 100 diam^m

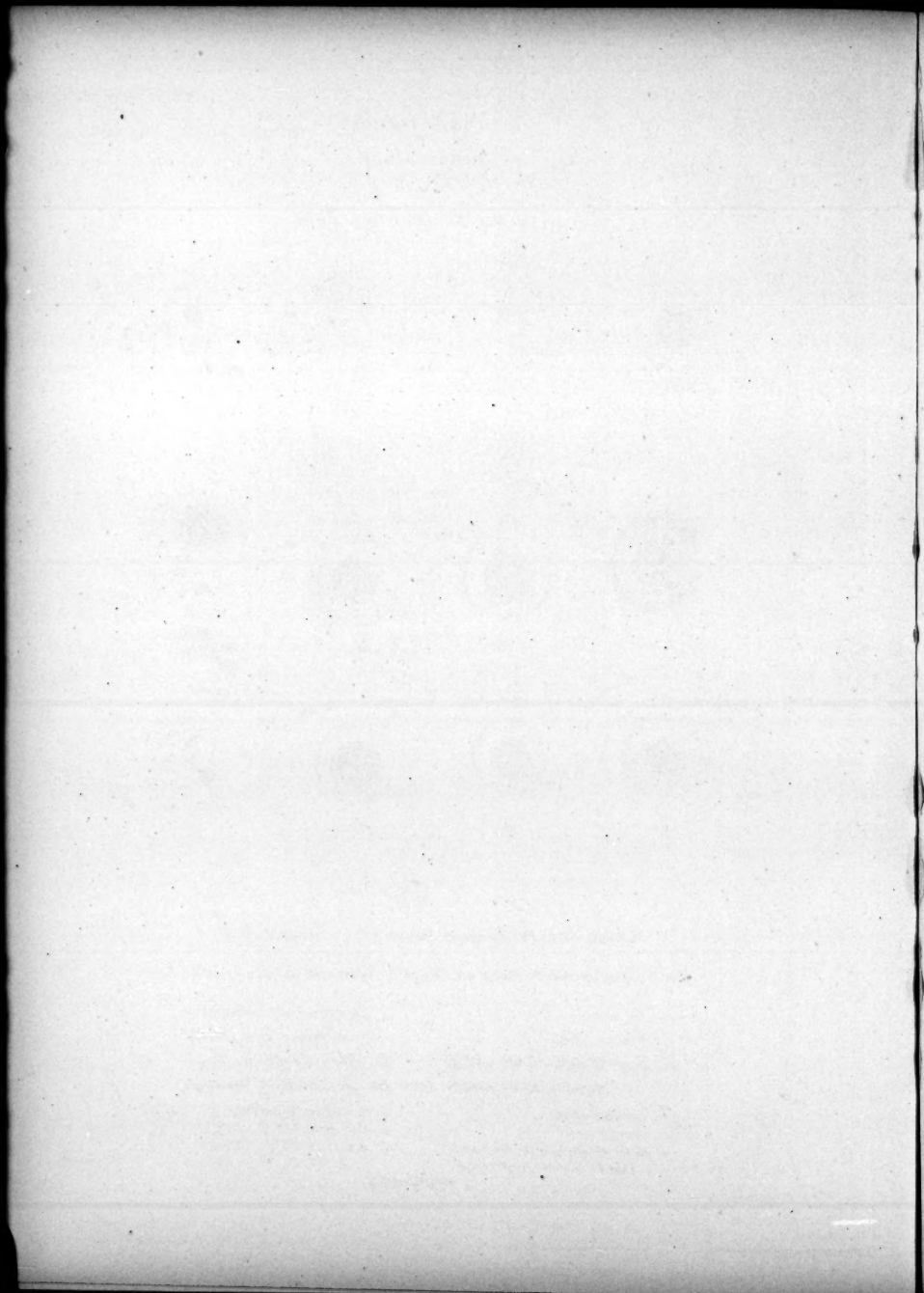
b.s. The Germ.

c Germinal Vesicle.

e Proper Membrane of the Substance
by which the Germinal Vesicle
is surrounded.

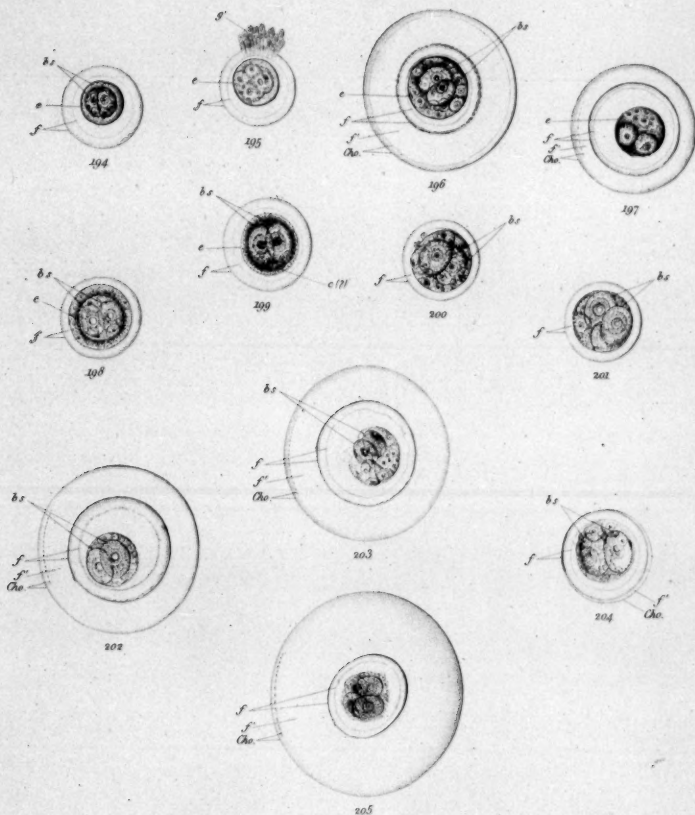
f Thick transparent Membrane of
the Ovum. "Zona pellucida".

f' Fluid imbibed by the Chorion.
Cho. Incipient Chorion (becoming
villous in the Uterus.)



Embryology.

Ova from the Fallopian Tube and Uterus.



Actual Sizes; Largest Ovum (-) Smallest (-)

(All the Objects are from the Rabbit, and all magnified 100 Diameters.)

bs The Germ.

e Germinal Vesicle.

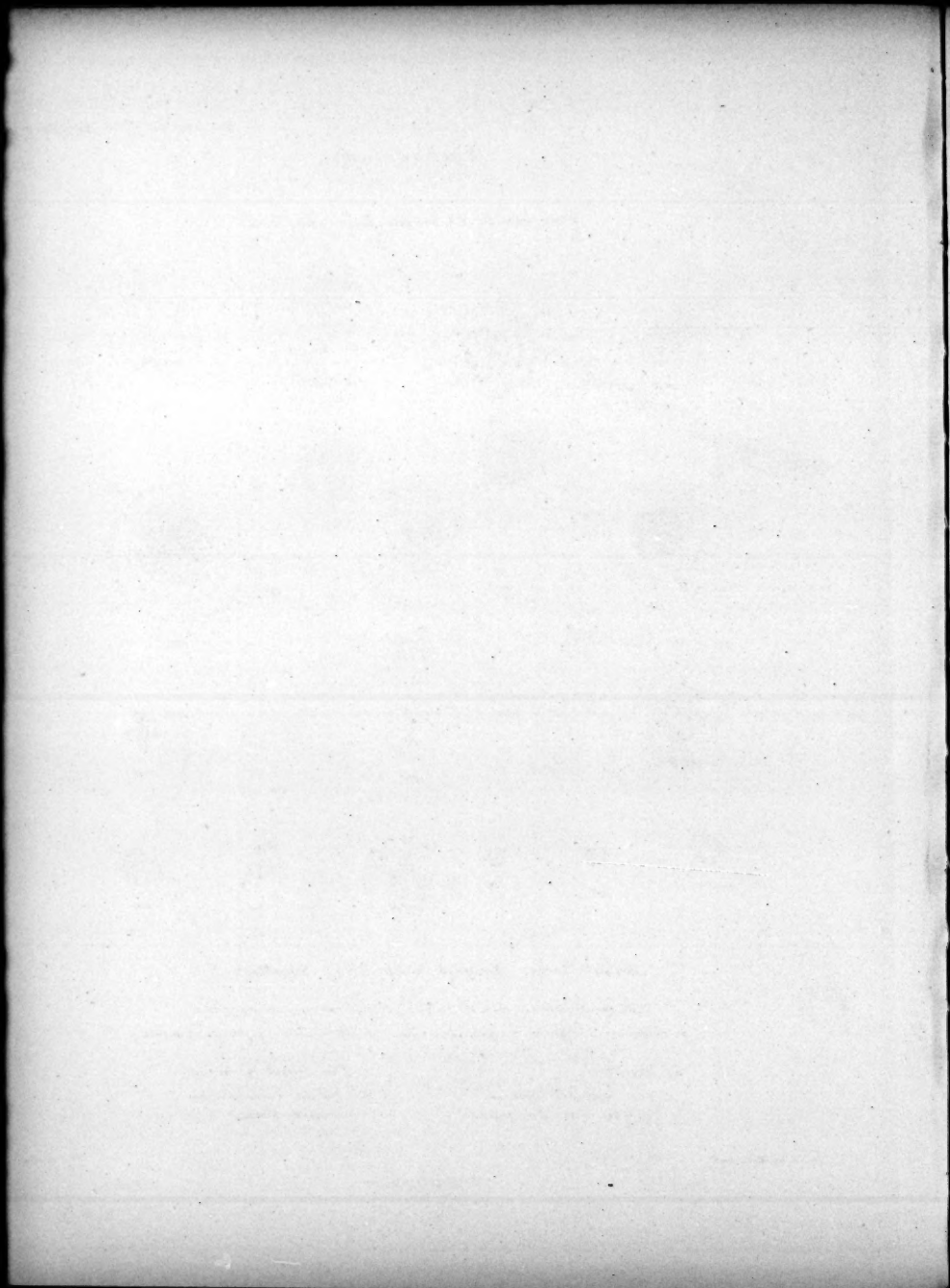
e Proper Membrane of the Substance by which the Germ. Ves. is surrounded.

f Thick transparent Membrane. Zona pellucida.

f' Fluid imbibed by the Chorion.

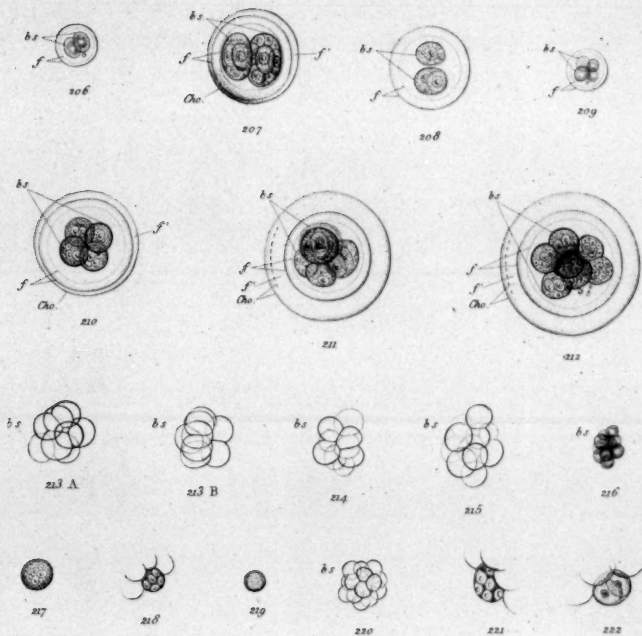
Cho. Chorion (becoming villous in the Uterus.)

g' Tunica granulosa.



Embryology.

Ova from the Fallopian Tube and Uterus.



Actual Sizes; Largest Ovum (·) Smallest (·)

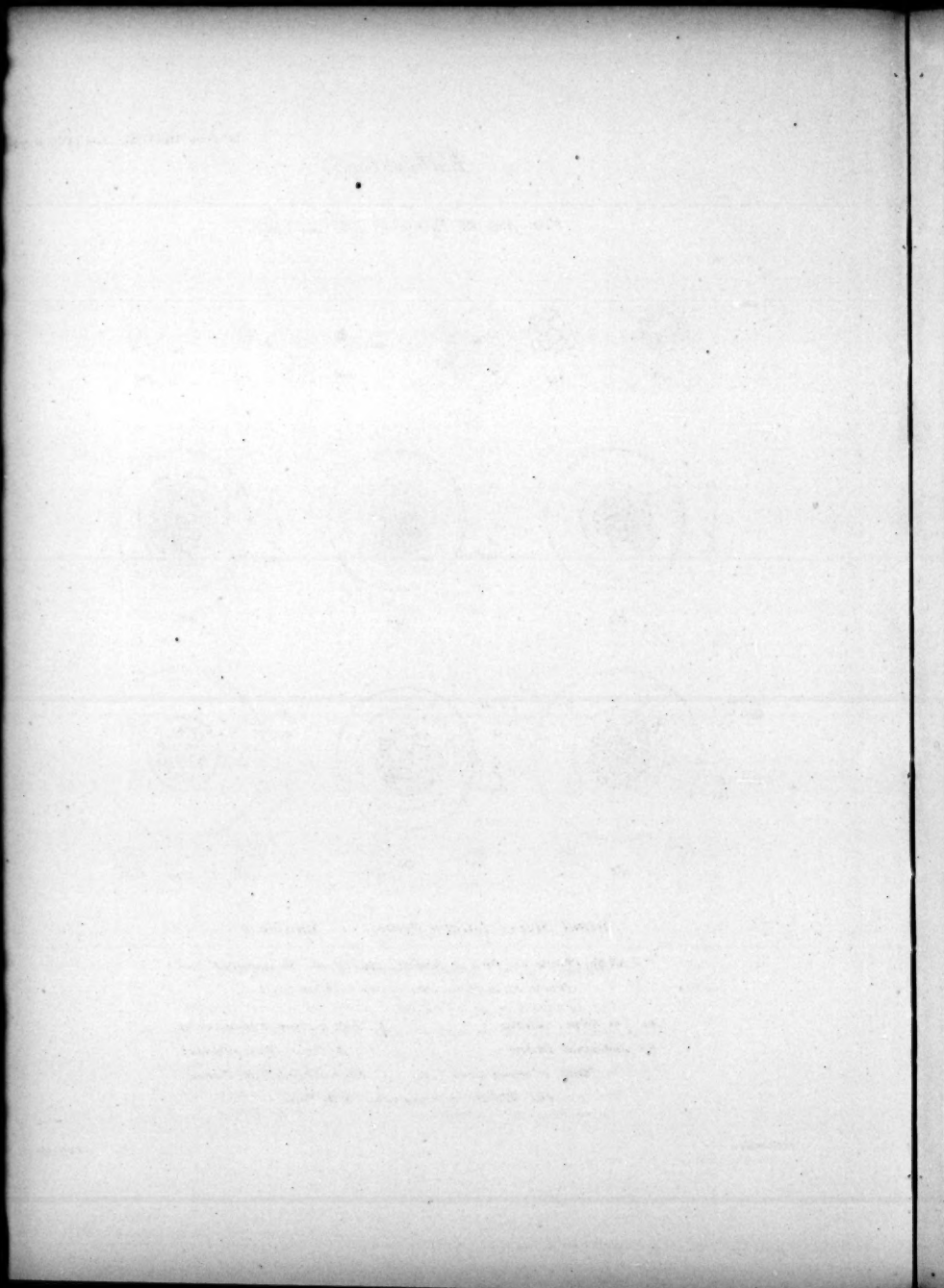
(All the Objects are from the Rabbit; — in Fig^s 206, 209, 216, magnified 50 Diameters; in Fig^s 221, 222, mag^d 300 Diam.; in all the other Figures 100 Diameters.)

bs The Germ.

f' Fluid inhibited by the Chorion.

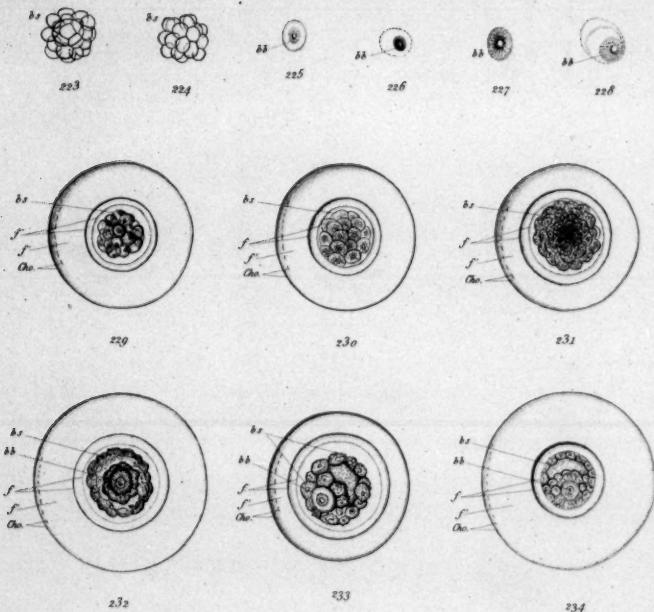
f Thick transparent Membrane
of the Ovum. "Zona pellucida"

Cho. Chorion (becoming villous
in the Uterus.)



Embryology.

Ova from the Fallopian Tube and Uterus.



Actual Sizes: Largest Ovum (·) Smallest (·)

(All the Objects are from the Rabbit; — in Fig^s 227, 228, magnified 300 Diameters, in all the other Figures, 100 Diameters.)

bs The Germ, including

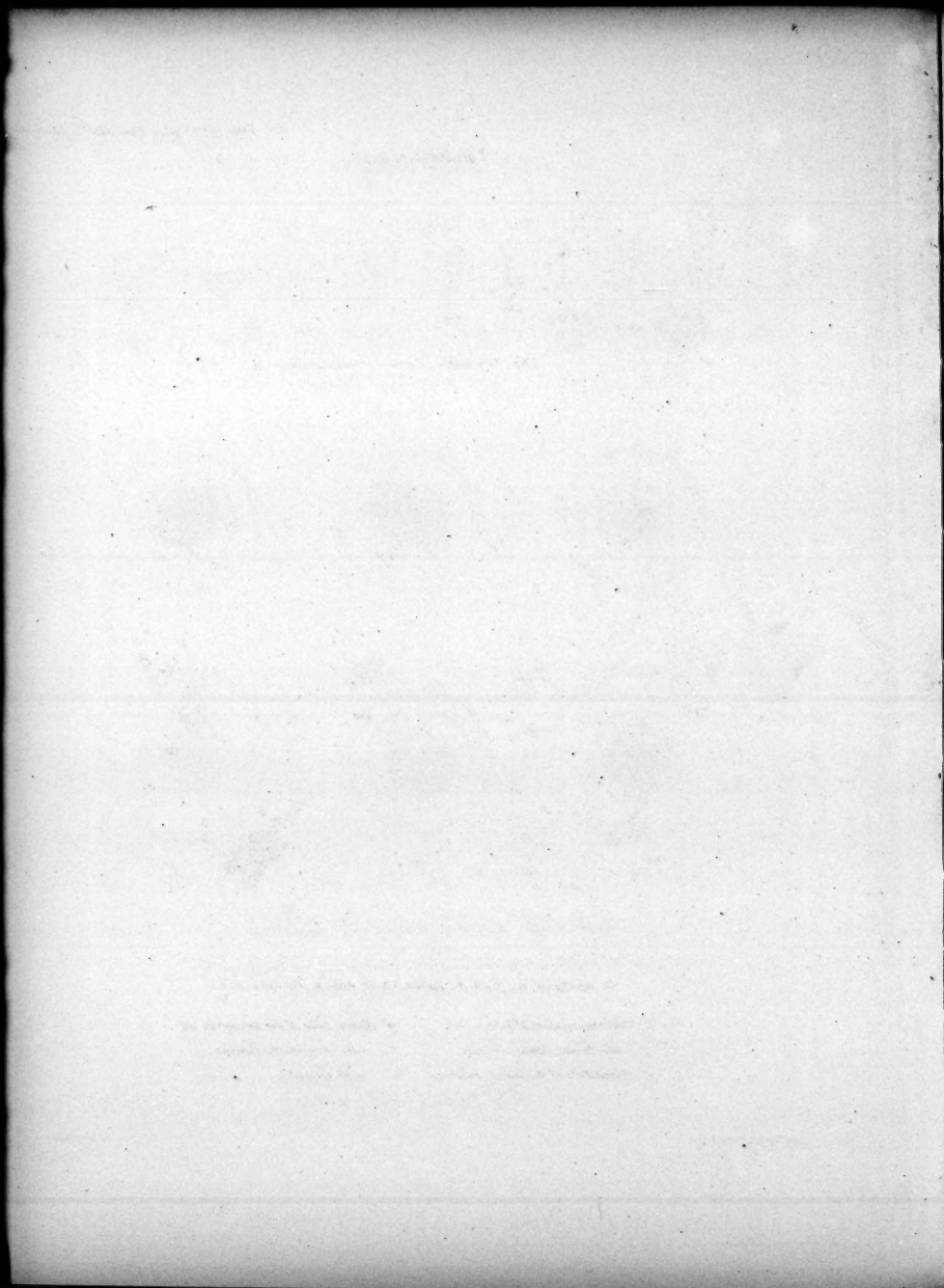
bb Rudimental Embryo —

— ("Germ" of second series.)

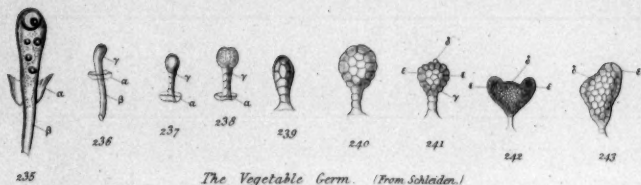
f Thick, transparent Membrane of the Ovum — "Zona pellucida"

f Fluid imbibed by the Chorion.

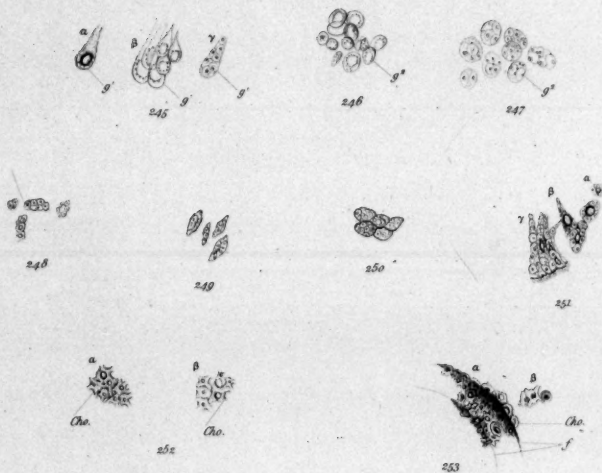
Cho. Chorion (becoming villous in the Uterus.)



Embryology.



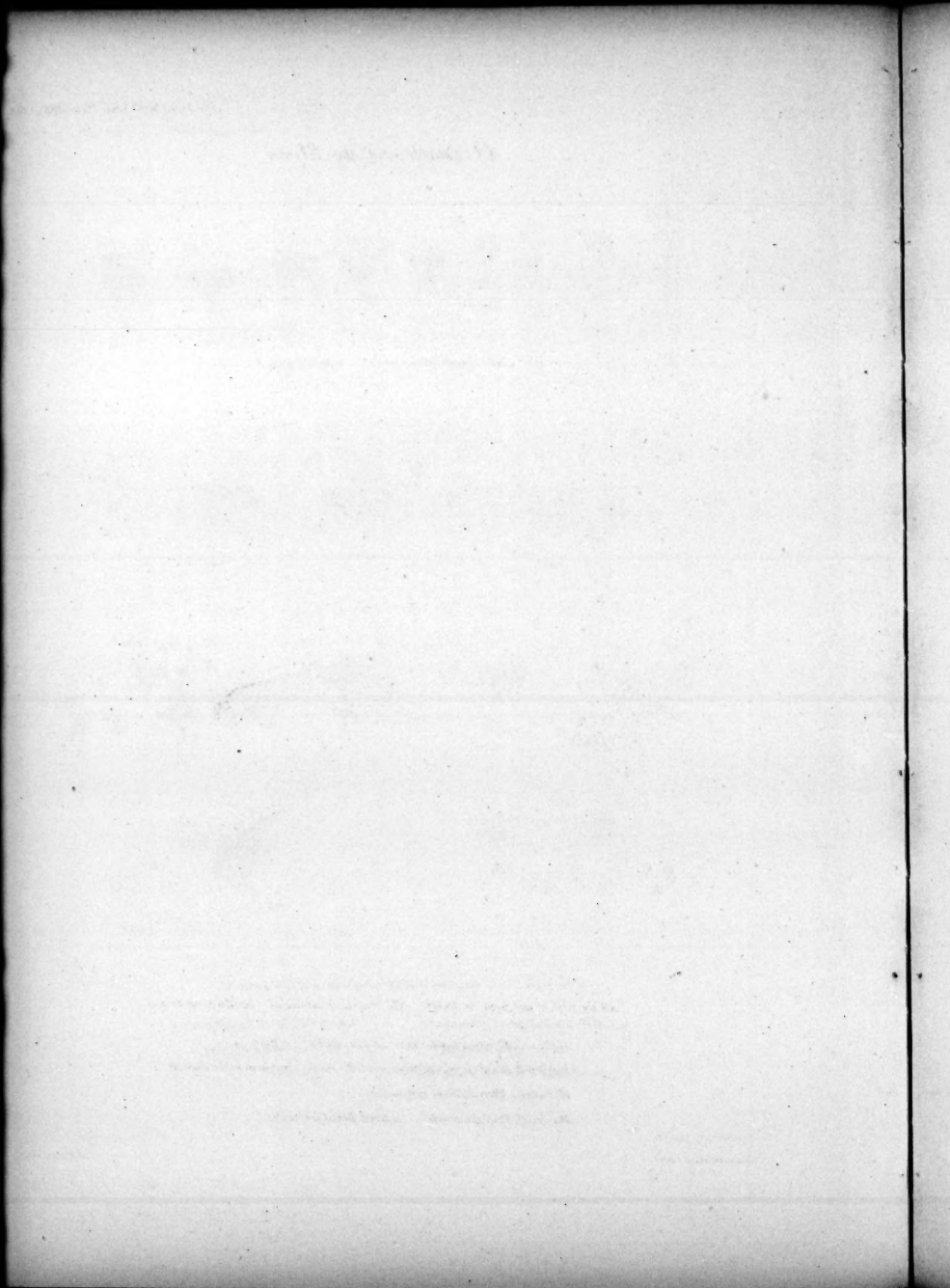
The Vegetable Germ. (From Schläden.)



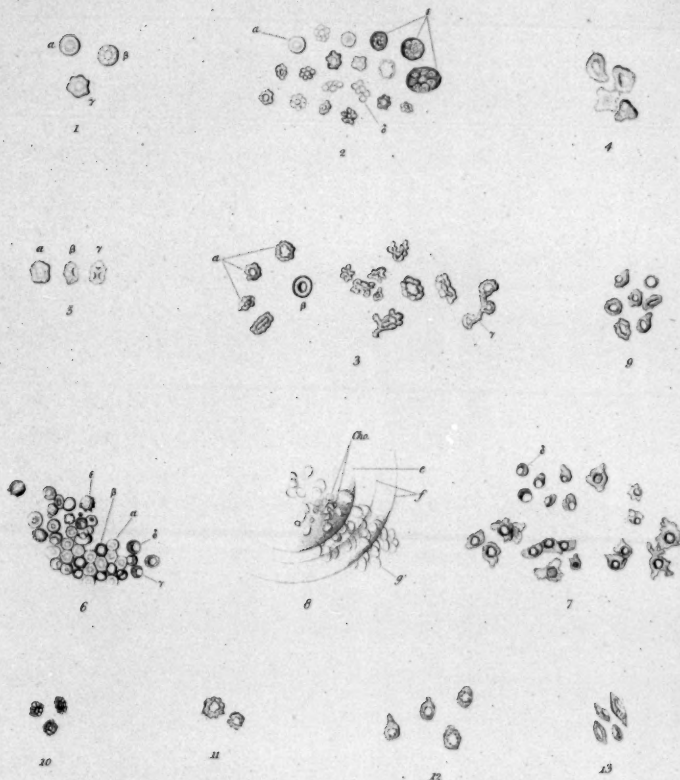
(All the Objects are from the Rabbit, except those in the upper line.)

f Thick transparent Membrane of
the Ovum. "Zona pellucida".
g Altered Cells of the Tunica granulosa.

g Altered Cells of the Retinacula ori.
Cho. Cells of which the Chorion
is formed.



Corpuscles of the Blood.



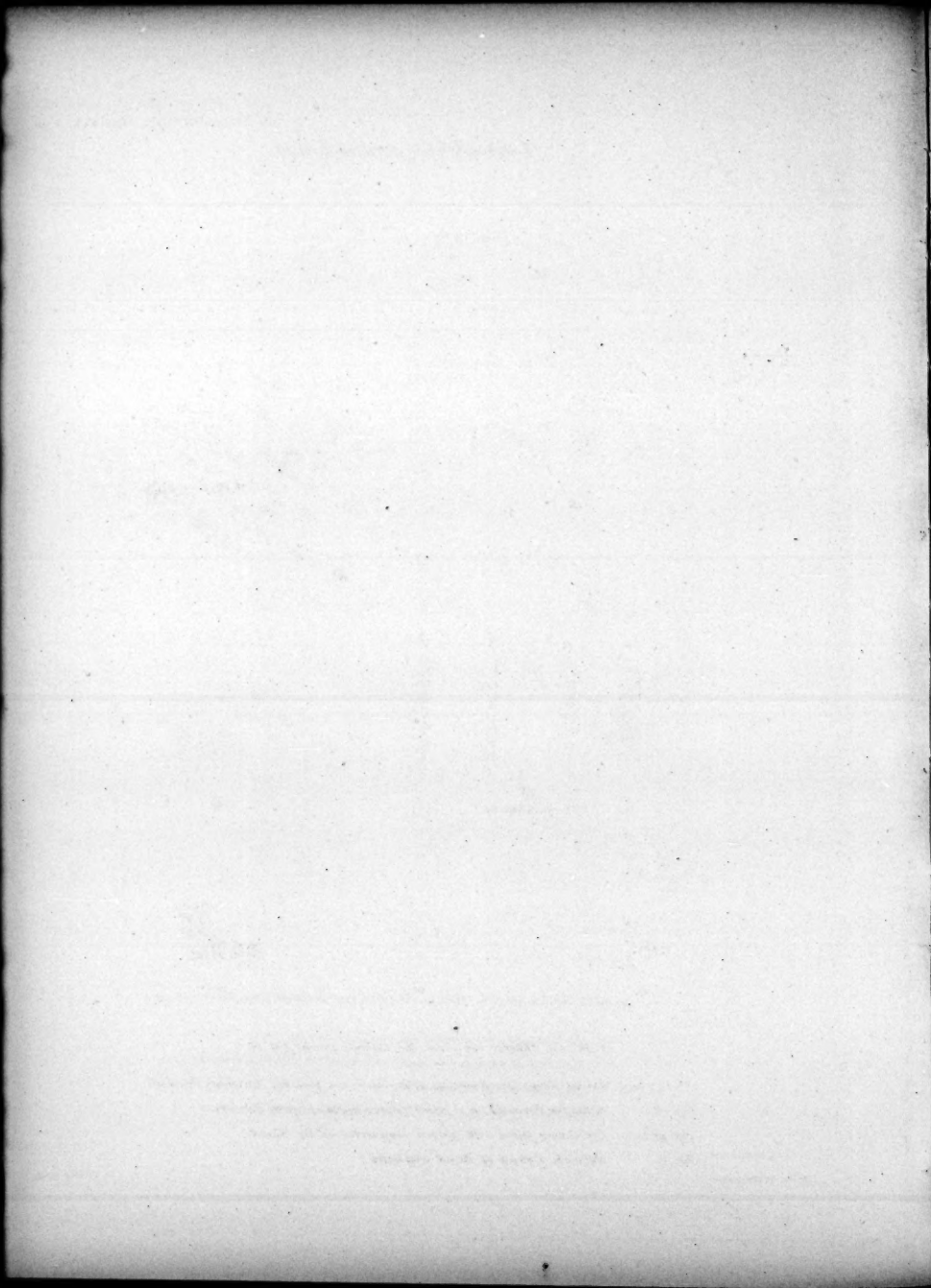
All the Objects are, from the Rabbit. The diameters magnified vary from 200 to 400.

Fig^s 1 to 5. Blood-corpuscles, more or less altered. (c Fig. 2.)

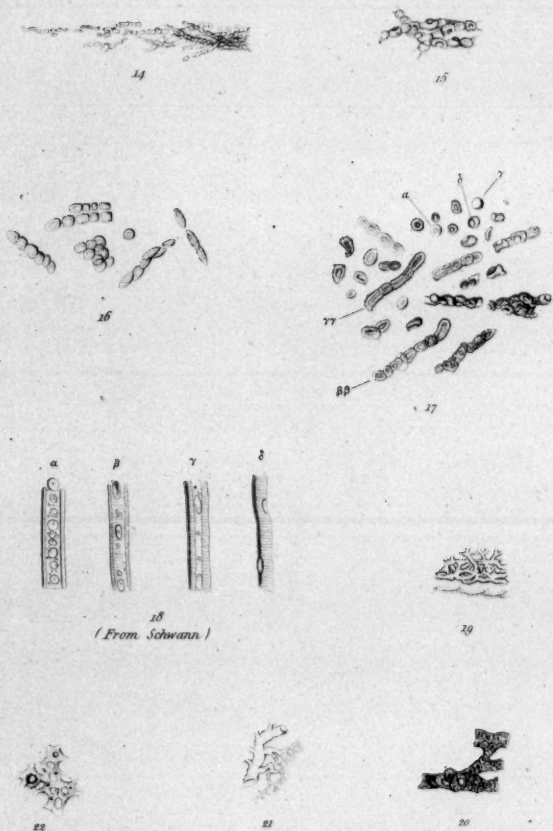
Fig^s 6 to 8. Blood-corpuscles, becoming Cells for the formation of the Chorion.

Fig^s 9 to 11. Altered Blood-corpuscles.

Fig^s 12, 13. Epithelium-cells. (Altered Blood-corpuscles?)



Corpuscles of the Blood.



(From Schwann.)

(All the Figures are from the Rabbit, except fig. 18.)

Fig^s 14 to 17. Blood-corpuscles becoming Cells, which are forming Muscular Fasciculi.

Fig. 18. Muscular Fasciculi in a more advanced state (from Schwann.)

Fig^s 19 to 21. Capillaries filled with altered Corpuscles of the Blood.

Fig. 22. Network, formed of Blood-corpuscles !